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GEOLOGICAL MAGAZINE

VOL. LXXXVII. No. 3. MAY–JUNE, 1950

Pleistocene Events in the Baringo Basin, Kenya Colony

By V. E. FUCHS

(PLATES IX–XI)

ABSTRACT

A study of the succession within the Lake Baringo Basin shows that the lake deposits originally described as Miocene by J. W. Gregory are of Middle Pleistocene age. In addition an examination of the relation between these deposits, the volcanic episodes and the periods of faulting, shows that climatic change has not been the major factor responsible for past fluctuations of the lake level.

PRELIMINARY NOTE

The map used for this work was the War Office GS.GS. 1/250,000 sheets $\frac{\text{north A–37}}{\text{S}}$ Baringo and $\frac{\text{north A–36}}{\text{X}}$ Uasin Gishu.

As the map-sheets north of this pair had not been published, it was necessary to extend the existing map as far as KARPEDDO. This was done as accurately as possible on a scale of 1/250,000, during the course of the geological work. Where altitudes are given, they are taken either from the GS. GS. map or from aneroid readings corrected in relation to a fixed twenty-four hour barograph. The rock specimens and field notes have been deposited in the Museum of Mineralogy and Petrology, Cambridge. Specimen numbers are given in brackets after the rocks referred to.

The field work upon which the paper is based was carried out in 1938 with the assistance of Dr. D. G. MacInnes, who was responsible for the important find of fossils in the Red Bed. I wish also to acknowledge the great assistance received from Dr. W. Campbell Smith in identifying the rocks and for suggestions concerning their relationships.

Though the six weeks spent at Baringo were a private venture prior to the Lake Rukwa Expedition, this would have been impossible if the Rukwa Expedition had not been sent into the field with the assistance of the Royal Society, the Royal Geographical Society, and the Trustees of the Godman Fund of the British Museum, to all of whom the author wishes to tender his acknowledgments.

Publication of this paper has been delayed firstly by the war, and later by service in the Antarctic.

INTRODUCTION

BARINGO is a small lake lying in the Kenya section of the Great Rift Valley, at an altitude of 3,100 feet. Though frequently visited by trading caravans it was not until 1892 that Professor J. W. Gregory made the first observations on the geology of the area. This work was published in *The Great Rift Valley*, but he enlarged and revised his geological observations after his second visit in 1919 (Gregory, 1921).

It was largely through his observations in the Baringo region that he was able to build up his geological succession in East Africa. Unfortunately, he was handicapped by the absence of fossils (Gregory, 1921, p. 203), not only in the correlation of local areas but in the fundamental dating of the whole succession. In particular, this was the case with his Kamasian deposits of the Baringo basin. For a variety of reasons (op. cit., pp. 105, 114, 199) he chose to date them as Miocene, and included them under his Nyasan Series.

Later, Dr. L. S. B. Leakey (1931A, p. 501) showed that some of the deposits tentatively correlated by Gregory with the Kamasian of Baringo were not of Miocene but Middle Pleistocene age. Later, when writing " The Geology of the Lake Rudolf Basin ", it seemed to me that on the strength of Arambourg's observations (Arambourg, 1935, p. 12) besides my own, the original Kamasian of Gregory would prove to be Miocene, as he had originally suggested. Therefore, in order to avoid confusion in the meaning of the term " Kamasian ", which had by then become generally used for Middle Pleistocene in East Africa, I proposed the use of Gregory's wider term Nyasan, to include the Kamasian deposits of Baringo (Fuchs, 1939, p. 229). The following indicates why I now believe that Gregory's type area of Kamasian deposits should be regarded of Middle to Upper Pleistocene age and should no longer be included under " Nyasan ".

A. Area West of Baringo (Type Area of " Kamasian ")

It was in this area that the greater part of our work was done, though certain observations on the east of the lake and in the Hannington area are recorded.

It is apparent that the lake now occupies a much smaller area than was once the case, and its present level is 120 feet below the overflow level at the northern end. If the water were to rise to this overflow, the axis of the lake, which now runs nearly 20° W. of N., would run 15° E. of N. These two directions are governed by the earlier N.–S. faulting and the later faulting with a N. 15° E. trend.

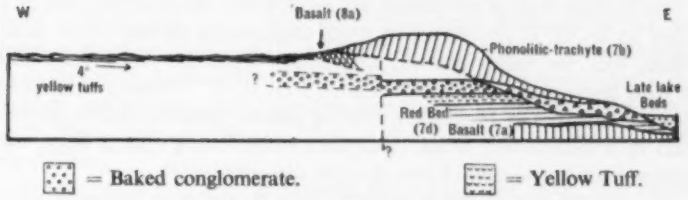
Before the faulting which gave rise to the present Lake Baringo, there extended over the area a much larger lake, in which were deposited the sediments which Gregory (1921, p. 114) regarded as being formed in " Lake Kamasia ". The greatest development of the Kamasian deposits is found between the foot of the Kamasian scarp and the present lake. They also extend northwards far beyond the bounds of the present basin, to the district west of Kinyang and Karpeddo. These sediments attain to 3,800 feet, but there is no present feature which could have formed the northern shores of such a lake, a point which will be discussed later.

(*a*) *The Kapthurin River Area*

The Kapthurin river proper rises in the foothills of the Kamasian escarpment under Kapthumo ridge, and reaches the lake just south of Kampi ya Samaki. After the river breaks through the last escarpment before reaching the lake flats it is joined by a tributary from the north, which follows an almost parallel course after rising only a few miles to the west under the Moguswak Hills. Since this tributary is also known locally as Kapthurin, it will here be called Kapthurin (north).

(i) *Kapthurin (North) Exposures.*

Where the Kapthurin (north) breaches the last escarpment on its way to the lake flats it has cut a steep-sided gorge, exposing the section incorporated in Text-fig. 1. Upon a base of purplish olivine-free



TEXT-FIG. 1.—Composite Kapthurin River Section.

basalt (7*a*) lies a red bed (7*d*) with some thin pebble bands, the whole being about 30 feet thick. The upper surface of the red bed has been eroded and later covered by a coarse rubble, but at the western end of the exposure the bed is complete, and is conformably overlain by a thin brown clay with carbonaceous remains. Above this comes a yellow clayey bed with some pumice and concretionary brown bands with calcareous nodules. The upper part of the series is obscured by scree, but a prominent conglomerate horizon has in place been hardened, apparently by the baking effect of the phonolitic-trachyte (7*b*) where it lies directly upon it. This lava at its western margin seems to rest upon a weathered olivine-basalt (8*a*), while to the east it has poured down the scarp over the exposed sediments and an angular rubble which overlies them. The conglomerate is probably the lower of two gravel horizons which will be seen to be widespread in the area.

Text-fig. 1 is a composite section compiled from several localities, which shows the local situation. In this section are shown what I believe to be the lowest known deposits of the Kamasian lake. From many sections in this locality it seems probable that there is normally an unconformity at the top of the Red Bed, but in the Kapthurin (north) sections this was not observed. In the Kapthurin river section, the Red

Bed is approximately 100 feet thick, as opposed to 30 feet at Kapthurin (north) and has a heavily eroded upper surface overlain by false bedded gravels entirely different in character to the conglomerate referred to above and clearly much later.

The fault suggested in the section is inferred from topography and the relative altitudes of exposures in the vicinity.

For some 3½ miles to the west of the above section the Kapthurin (north) valley is cut through yellow pumiceous sediments dipping steadily E.S.E. at 4°. To the north and west these beds are capped by a phonolitic-trachyte (11*a*) of similar type to that already mentioned (7*b*).[1] From its situation as an extensive lava overlying the lake deposits one might have expected this to be one of Gregory's Laikipian basalts, but apparently these later phonolites are more widespread than he had thought.

At 4½ miles west of the section the pumice beds become disturbed and dips up to 12° E. are visible in small undulations having N.–S. axes. Here, too, the valley receives a tributary from the north, exposing similar pumiceous beds with a dip of 9° N.N.W. Turning westwards towards the foot of Moguswak Hill the yellow pumiceous bed is underlain by a reddish clay which disappears within half a mile to allow the yellow beds to rest upon 8 feet of white diatomite (11*b*).

As will be seen in other sections, this diatomite is extensive, and wherever the base is visible a thin band of fish bones and scales (*Tilapia* sp.) divides it from an underlying brown argillaceous sand. At the foot of Moguswak Hill all the deposits thin out, and it is evident that here was the shore line of the old Lake Kamasia.

Moguswak Hill itself is formed of an altered purple olivine-basalt (12*a*), boulders of which (19*b* (*f*)) were found in the false bedded gravels which lie unconformably upon the Red Bed (see above).

(ii) *Kapthurin River (Proper).*

The Kapthurin River proper similarly cuts through a lava (33*a*) overlying the Red Bed. The Red Bed here has a westerly dip of 14° and lies upon a purple-weathering basalt (33*c*) which forms the floor of the river bed and is similar to, if not identical with, the flow (7*a*) of Kapthurin (north).

On the south side of this valley the yellow tuffs are absent and the Red Bed is approximately 100 feet thick, with an eroded upper surface upon which lies an unconformable series of gravels and sands. Here, in the extensive exposures of the Red Bed, Dr. D. G. MacInnes found fragments of bone, including those of *Elephas* sp., *Phacochoerus* sp., (?) *Giraffa* sp., and two species of antelope, besides numerous specimens

[1] Dr. Campbell Smith states that both (7*b*) and (11*a*) are similar to a rock collected by Gregory (G 311) and described by Prior (1903, 241).

of the mollusc *Melanoides tuberculata* (Muller) and fish remains. As Dr. MacInnes remained in East Africa, he has not been able to study the material since field identification was made. Dr. A. T. Hopwood has, however, seen the specimens and declares the hippopotamus to be a large form comparable to *H. amphibius*, which must be of post-Miocene age. He also expresses the opinion that the whole assemblage is certainly not pre-Plio-Pleistocene and is most probably of Middle Pleistocene age. This is confirmed by the presence of *M. tuberculata*, for as I have shown (Fuchs, 1939, p. 252), the present nilotic molluscan fauna of which *M. tuberculata* is typical did not reach Lake Rudolf from the Nile until Middle Pleistocene times, and it seems certain that this must have been the route by which it entered the Baringo basin.

West of the above exposures the Kapthurin River is bounded by steep cliffs of pink sandy beds containing large quantities of yellow pumice which dip east at 4–5°, and are the same beds as those already described from the Kapthurin (north). The upper part is crowded with kunkar and gravel, which indicates deposition in shallow conditions with fluctuating periods of precipitation during normally drier conditions.

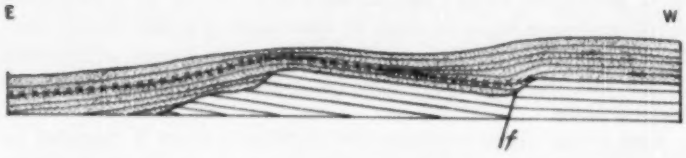
On the south side of the Kapthurin River gorge and in the next small stream bed to the south, the Red Bed persists, having there an apparent dip of 5° to the north-west. Conformably overlying it are fine gravelly beach deposits with coarser bands from which come the majority of the boulders that now litter the eroded slopes of the Red Bed. Among these boulders are numerous artifacts of early Levallois type, and it is tempting to conclude that these implements are coming from the pebble bands of the Red Bed. A few specimens (flakes) appeared to be *in situ*, but as their position was on the extreme edge of a weathering pebble bed the occurrences cannot be claimed with certainty. These implements appear to belong to the culture which Leakey (1931B, p. 34) has called Nanyukian, and which elsewhere in the rift valley occur at the end of the Middle Pleistocene.

In certain of the gullies immediately south of the Kapthurin River, the purplish boulder bed in the Red Bed thickens, and with the rest of the series increases its dip to 10° N.W. Locally there is a small fault which downthrows some 6 feet to the east, but this has not affected the sands and clays which here overlie the Red Bed unconformably. These sands and clays contain a whitish band of shelly-limestone and attain an altitude of approximately 3,625 feet. Unfortunately, it has not been possible to identify any of the very fragmentary shell remains included in this limestone, but some are certainly land forms. As can be seen from Text-fig. 2, these upper beds are in part pseudo-conformable to the Red Bed, which seems to

indicate that both series have been tilted since the deposition of the later beds.

Conclusions from the Area of the Kapthurin Rivers.

On faunal evidence it is now considered that the earliest known lake beds of Gregory's " Lake Kamasia " are of Middle Pleistocene age, and not Miocene as he originally suggested. This conclusion is supported by the existence of a stone tool culture of early Levallois



TEXT-FIG. 2.—Deposits of the 3,575 ft. lake rise resting unconformably on faulted red bed.

affinities, though some degree of uncertainty surrounds the exact origin of the implements.

An outburst of volcanicity gave rise to a thick series of aqueous and subaerial tuffs which in places lie conformably upon the Red Bed itself but are more usually unconformable. This volcanicity continued while the lake rose during a period of increasing precipitation (and/or barrier-building, as will be seen later) and finally attained to a level of 3,800 feet. Towards the end of this period of lake rise the volcanic outbursts ceased and were followed by a period of quiet during which diatomites were formed and fish returned once more to the lake.

It is concluded that the Red Bed was formed during the interpluvial period at the end of the Middle-Pleistocene, and that the subsequent lake rise and volcanics occurred at the time of Leakey's Gamblian (Leakey, 1931A). The diatomite and associated deposits would therefore be equivalent to the 220 ft. beaches of Lake Rudolf, to the north (Fuchs, 1939, figs. 8 and 9).

After this the Lake fell, prior to a second rise which is here represented by the sandy beds with a shell band which lie unconformably across the faulted and eroded surface of the Red Bed.

(*b*) *The Area West of Marigat*

The ford of the Tiggeri River at Marigat Post is that referred to by Gregory (1921, p. 111). A few yards west of the ford the river has cut a vertical-sided gorge through a thick phonolite (4*a*) which overlies a glassy soda-trachyte (4*b*) (Plate IX, fig. 2). West of the gorge the Tiggeri,

flowing from the south, receives a tributary from the west which will be called the Marigat River for want of a local name.

(i) *The Tiggeri River.*

Some ¾ mile up the course of the Tiggeri, above the ford, the lavas are abruptly faulted out and the cliffs are formed of a series of pinkish sediments which are probably a southern extension of the post-Red Bed deposits of the Kapthurin area. These deposits overlie a soda-trachyte (55*e*) which appears to be the down-faulted representative of the uppermost lava (55*a*) on the west of the fault. The throw of the fault, which cuts the series of basalt and soda-trachytes (55*a–d*), is of the order of 80 feet. That the fracture occurred before the deposition of the sediments, and before the lake in which they were deposited extended over the area, is deduced from the occurrence of a coarse red sand and gravel left by a stream which was evidently cutting its course along the strike of the fault before the rising lake was floored first with the basal boulder bed and later the overlying sands and gravels.

This fault appears to belong to the series of N.–S. faults to the east of Marigat Post (p. 158). Half a mile further up the Tiggeri a number of small N.–S. faults, having a normal downthrow to the east, was seen. The aggregate throw of these faults is only some 30 feet, but immediately to the south-west there is another but greater fracture of some 70 feet throw having a similar direction.

(ii) *The Marigat River.*

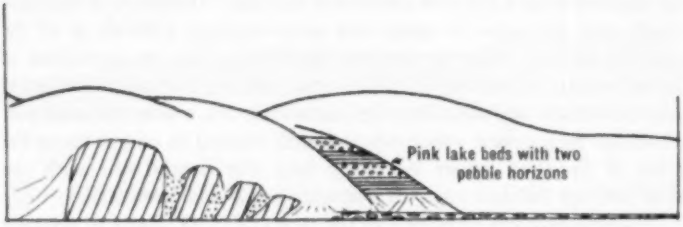
Shortly above its junction with the Tiggeri River the Marigat provides a 75 yard section in its south bank which, though small in scale, serves to show the highly disturbed nature of the deposits. On the left of the section a fault lets down the sediments against a soda-trachyte (35*a*), which microscopically appears to be the same rock as (55*a*) and (55*e*). Here, however, the direction of all the faults is approximately N.W.–S.E., and they also affect the sedimentary series ; it therefore appears probably that they belong to a later period of movement.

About ¼ mile above this section there is another short and narrow gorge (Text-fig. 3) which has been cut by the river through an analcitic-phonolite (36*a*) with trachytic texture. This gorge may be called the second Marigat Gorge. The rock through which it is cut has the superficial appearance of an enormous dyke with vertical walls on east and west, but unfortunately, owing to scree it was impossible to see the contact with the lake sediments. On the east side of the gorge large masses of trachyte, like fallen pillars, have been detached from the main mass by the undercutting action of water seepage through the sediments.

It is likely that this represents an extrusion of a lava which occurred shortly before the lake attained its maximum in Upper Pleistocene

times. In yet another gorge (Third Marigat Gorge) a short distance to the west, a rock (46*a*), of similar character, but with occasional phenocrysts of altered olivine, overlies sediments which it has baked a deep red. This lava has a marked basal rubble and was clearly extruded on the surface.

The fallen blocks of the Second Gorge lava have between them a filling of material derived from the lake deposits seen in the background of Text-fig. 3. That a powerful river flowed over the lava



= Pink unstratified deposits probably derived from lake bed series.

= Calcareously cemented boulders of old Marigat river, cut by present river.

= Analcitic phonolite (36*a*) with trachytic texture : fallen blocks due to back cutting by river.

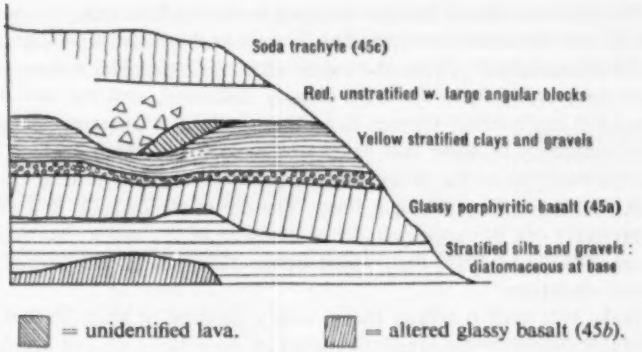
TEXT-FIG. 3.—Section through the Second Marigat Gorge.

before the falling of the detached blocks is shown by the existence of a huge pot-hole some 10 feet in depth, its vertical axis now being inclined at a steep angle. Similar pot-holes are cut into the top of the lavas on the south side of the Marigat River just west of the point where it joins the Tiggeri. These pot-holes indicate a period of very active erosion subsequent to the retreat of the lake from its maximum in the Upper Pleistocene (Gamblian) when the present system of drainage was initiated. The volume of water then carried by the rivers must have been far in excess of any known even in the rainy seasons to-day.

Two other points are noteworthy in this section. The first is the occurrence of two thick gravel horizons in the lake sediments. These extend over a wide area and appear to represent two periods of lake retreat before it attained to its maximum. The second point is that the present river bed has been cut through an older river deposit, of which the boulders are cemented by a calcareous matrix. This earlier river bed evidently represents a period of aridity when erosion was even less than at present.

About ¼ mile west of the Third Marigat Gorge one approaches the shores of the old lake at the time of its maximum extent, and Text-fig. 4 shows the section there exposed. The lowest rock is a much altered

glassy basalt (45*b*), overlain by a very impure diatomite passing into earthy material at the top. On the eroded surface of this lies another glassy porphyritic basalt (45*a*) which was in its turn eroded and then capped by a series of yellowish stratified earths and gravels with a basal pebble bed. Erosion again cut a gulley into these deposits, which was then filled with a lava of which no specimen could be obtained.


Soda trachyte (45c)
Red, unstratified w. large angular blocks
Yellow stratified clays and gravels
Glassy porphyritic basalt (45a)
Stratified silts and gravels : diatomaceous at base
= unidentified lava.
= altered glassy basalt (45b).

TEXT-FIG. 4.

The greater part of this gulley-filling was then removed and the small valley so formed filled with reddened material containing large angular blocks. The whole series was then capped by a very fine-grained soda-trachyte (45*c*).

Thus this section shows the fluctuation of the old lake at its maximum extent and indicates the complexity of events in this region, where successive volcanic products were formed upon a land surface continually modified by erosion or deposition during periods of lake rise and fall.

(iii) *Conclusions from the Area West of Marigat Post.*

In this area extensive phonolitic-trachytes and trachytes were faulted by N.–S. fractures before the deposition of the overlying lake deposits. The latter are sands and gravels, with diatomite in the vicinity of the old shoreline. There is evidence of continued volcanicity during the deposition of these sediments which appear to have been formed in a rapidly rising lake. Before attaining its maximum level at approximately 3,800 feet there were at least two periods of temporary retreat, shown by twin gravel horizons of considerable thickness and extent.

The fall of the lake from its maximum appears to have been even more rapid and permitted heavy erosion of the volcanics and lacustrine deposits. At this time also a second period of faulting occurred, this

time N.W.–S.E., cutting through the lake deposits but not disturbing the general E.–W. direction of drainage.

Finally the calcareously cemented boulders of an earlier bed of the Marigat river suggest a comparatively recent period of aridity greater than the present.

(*c*) *The Area South and East of Marigat Post*

To the south-east of Marigat Post are numerous fault valleys running N.–S., and these features extend as far east as the Bogoria swamp and Lake Hannington. From the occurrence of Upper Pleistocene lake beds up to 3,800 ft. in the areas already discussed, and the fact that the 3,800 feet contour appears in all these valleys, it was expected that representatives of these lake beds would be found there also. This proved to be so in the valley running south on the east side of Duka Hill, ½ mile E.S.E. of Marigat Post. The dip of the beds (5° W.N.W.) is probably one of deposition, for at the head of the valley they attain to an altitude of 3,805 feet, which agrees closely with the maximum found elsewhere.

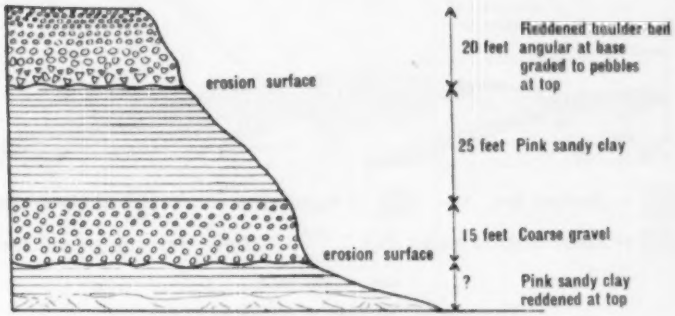
Duka Hill itself is a fault block, with a capping of some 20 feet of boulders similar to the boulder capping of the plateau west of Marigat referred to be Gregory (1921, p. 111). Beneath these boulders comes a 60 ft. band of coarse red-brown sandstone (5*a*) which lies on 50 feet of a spherulitic phonolite (5*b*). In the middle of the sandstone is a 12 ft. band of gravel with yellow tuffs and pumice, all false-bedded and forming prominent cliffs. It is worthy of record that a single humanly struck flake appeared to have come from these gravels (5*c*). These sediments are perhaps equivalent in age to the Red Bed at Kapthurin. To the south they disappear beneath scree and rubble, and the entire scarp is formed of an anorthoclase-trachyte (40*b*) which is capped to the west by an olivine-basalt (42*a*). These lavas, therefore, appear to be the eastern extension of those found in the Tiggeri River section (p. 155). The occurrence of the boulder bed as a capping for Duka Hill can only be explained by assuming the fault valley to have been filled by lake sediments subsequently removed by erosion. This would agree well with the sequence of events in the Tiggeri River.

(*d*) *Nasagum River Exposures.*

The Nasagum, which lies between the Marigat and Ndau Rivers, has a wide river bed with precipitous cliffs throughout the greater part of its length (Plate IX, fig. 3), and except after rains is normally dry.

The valley is floored with a phonolite (49*a*) having radially arranged feldspars, in which it resembles (40*a*) and (5*b*) of the Marigat area. Upon this phonolite rest typical lake beds dipping 5° E.N.E. in the eastern part of the exposures.

About 1½ miles up river from where it debouches on to the lake flats the basal lava rises to form the 30 ft. walls of a narrow gorge. West of the gorge the lava ends abruptly and the valley widens to ¼ mile, with steep cliffs of pink lake sediments, including two prominent gravel horizons. The succession is shown in Text-fig. 5. At the base are pink sandy clays, becoming redder towards the top, which suggests increasing aridity. Between the top of these clays and the overlying 15 feet of gravels is a disconformity marking a retreat of the lake at this time. The subsequent rise of the lake and a repetition of the above conditions is shown by 25 feet of pink sandy clays which overlie these lower gravels



TEXT-FIG. 5.—Section in the Nasagum River.

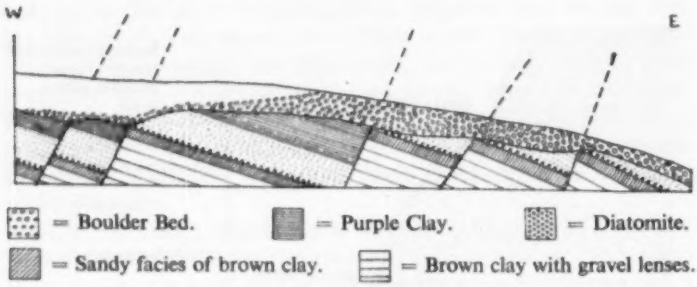
and above which is a second disconformity below 20 feet of coarse gravel having large angular components at the base and much reddening towards the top.

About 2 miles further up the Nasagum the river again narrows to pass through a gorge cut into a very fine-grained basalt (51*a*). This rock weathers into nodular masses and is columnar in the upper part. Here, the lower part of the sediments is not seen, but the lava is overlain by the upper gravels of Text-fig. 5. After passing through this gorge and turning west the valley opens out again ; the basalt (51*a*) is now 40 feet thick and lies upon lake beds having an apparent dip of 17° N., due to faulting. It therefore seems that both the faulting and the extrusion of the lava took place before the second gravel bed of Text-fig. 5.

West of this last point the lake beds resume their normal nearly horizontal dip but lose their characteristic pink colour, becoming grey to white. Here, too, the whole series, including the gravel horizons, are covered by another fine-grained basaltic lava (52*a*) having a maximum thickness of about 100 feet, which extends north and south of the river, and is doubtless the southern extension of the basalt mentioned by Gregory (1921, p. 112) in the Ndau valley immediately to the north.

In a tributary entering the Nasagum from the south, the capping lava could be seen to have flowed down the slopes of the valley across the eroded edges of the sediments ; thus, it was clearly extruded, not only after the lake maximum but some time after the present drainage system had been established.

Further up the Nasagum, at the point where the Marigat–Kabarnet track crosses the valley, are extensive exposures of faulted lake sediments. One of these sections is shown in Text-fig. 6. At the base is a brown clay with fine gravel lenses and concretionary bands about



TEXT-FIG. 6.—Section in Nasagum Valley.

1 foot apart. Above comes a more sandy but impersistent facies of the clay. Above this sand or the clay comes a thin, light brown, sandy fish-bed, crowded with scales and vertebrae (*Clarias* sp. and *Tilapia* sp.), which thickens eastwards to a maximum of some 6 inches, but at the same time becomes less rich in fish remains. Conversely the diatomite, which overlies it and was observed to be at least 12 feet thick, thins out towards the west, where it may be reduced to 18 inches.

The whole series has been cut by a number of faults running approximately 10° E. of N. These unexpectedly downthrow to the west, but the dip of the deposits remains consistently eastward, varying from 18° in some fault blocks to 38° in others.

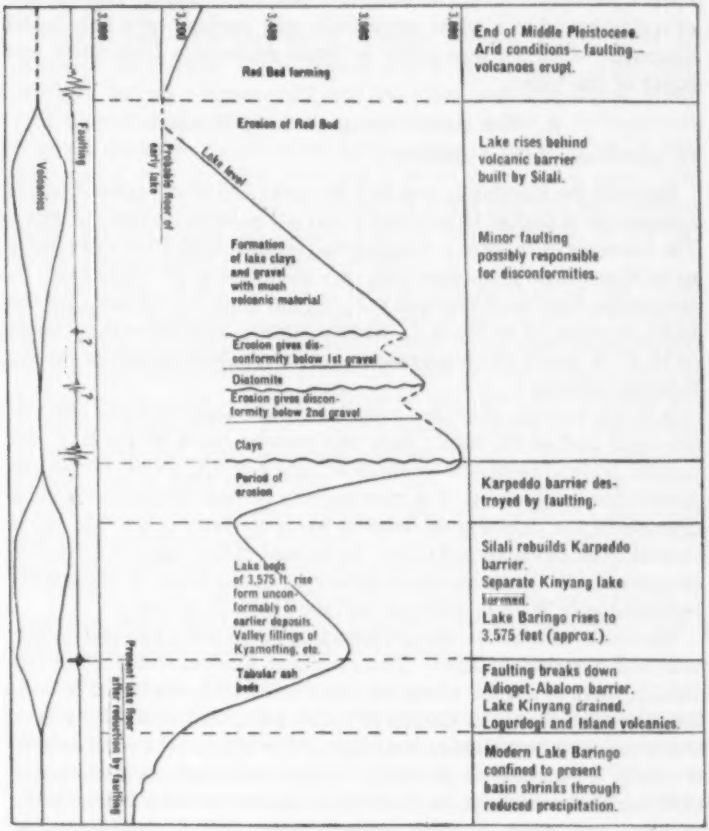
There can be no doubt that these sediments are the southern extension of the diatomite, with basal fish bed seen in the Kapthurin sections, and that they continue southwards to link with the diatomaceous deposits of the Marigat River.

As shown in the section this diatomaceous series has been faulted and heavily eroded before the deposition of the overlying gravels and sandy clays. Though unproved, I believe these gravels to be the local representatives of the second gravel horizon referred to above. If this is so, then the diatomite was formed in a period of volcanic quiescence

between two lake retreats shortly before the water rose to its maximum extent (Text-fig. 7).

Conclusions from the Nasagum River Exposures.

The Nasagum sections clearly demonstrate the continuity between


3,000
3,250
3,400
3,600
3,800
Red Bed forming
Erosion of Red Bed
Probable floor of early lake
Lake level
Volcanoes
Faulting
Formation of lake clays and gravel with much volcanic material
Erosion gives disconformity below 1st gravel
Diatomite
Erosion gives disconformity below 2nd gravel
Clays
Period of erosion
Lake beds of 3,575 ft. rise form unconformably on earlier deposits. Valley fillings of Kyamotting, etc.
Tabular ash beds
Present lake floor after reduction by faulting
End of Middle Pleistocene. Arid conditions—faulting—volcanoes erupt.
Lake rises behind volcanic barrier built by Silali.
Minor faulting possibly responsible for disconformities.
Karpeddo barrier destroyed by faulting.
Silali rebuilds Karpeddo barrier.
Separate Kinyang lake formed.
Lake Baringo rises to 3,575 feet (approx.).
Faulting breaks down Adioget-Abalom barrier.
Lake Kinyang drained.
Logurdogi and Island volcanics.
Modern Lake Baringo confined to present basin shrinks through reduced precipitation.

TEXT-FIG. 7.

deposits observed in the Kapthurin and Marigat areas. The lake beds here lie upon a floor of phonolites and are overlain by basalts.

The most striking features of the deposits are the two prominent pebble beds which are clearly the northern extension of those seen in the Marigat valley. Each is based upon a disconformity, and it may be that the retreat of the lake is in each case due to earth movement rather

than climatic change. Evidence for this conclusion is found in the extension of what is probably the higher gravel and associated sediments across the eroded edges of the faulted diatomite series.

Gregory's records from the Ndau River show little difference from the Nasagum sections, for there also the lake clays and gravels lie upon a phonolite and are themselves overlain by a basalt. His mention of a clay baked to a white porcellanite may perhaps refer to a baked diatomite which we now know to occur extensively both north and south of the Ndau.

B. The Area North of Lake Baringo

(i) *Loruk and Adioget–Abalom.*

Between the Kapthurin area and the north end of the present lake is a large area of faulted lavas which it was not possible properly to study. The examples of rocks (e.g. 95*a* and 96*a*) brought back from there prove to be Kenya-type phonolites with very abundant small nephelines. In general the faulting of this area is N.–S., but there is a tendency for the faults to swing off to the N.E., thereby coming into line with a swarm of N. 15° E. faults which appear around the southern margin of the old Korossa volcano.

It is this faulting which has provided the drowned coastline effect at the north end of the lake. Near the extreme north of the lake two parallel faults downthrow to the S.W. and run S.E.–N.W. across the general trend of faulting. The most easterly of these continues for some distance in the direction of Salawa, where it forms a low tuff scarp capped by an olivine-basalt (63*a*). To the east of this fault are a number of minor E.–W. fractures which appear to be the result of adjustment between the N.W.–S.E. fractures and the N. 15° E. group.

The rocks affected by these intersecting faults are water-laid yellow tuffs and a variety of lavas. Thus, Adioget-Abalom (hill 3580 of the GS.GS. map) is a small triangular horst in which a weathered phonolite (59*a*) overlies at least 120 feet of yellow tuffs. This rock (59*a*) is very similar to (92*a*) from Salawa waterhole, a few miles to the north, which is clearly a Kenya-type phonolite. Again, the spherulitic phonolite (93*b*) which forms the lower part of the fault face immediately N.W. of Loruk and which underlies yellow aqueous tuffs is another of this series of phonolites which may have originated from the early eruptions of Korossa.

In the vicinity of Adioget-Abalom the relation of the lavas and tuffs to the faulting is largely obscured by a later series of tabular tuffs banked up against the fault scarps. These later tuffs are very recognizable from their peculiar flaggy nature and are clearly the same as those observed along the west shore of the lake (and in particular at Kampi ya Samaki). They are considered to belong to the last phase of

volcanic activity which formed the island of Ol Kokwa and its associates, and are always the latest deposit where they occur. It is noticeable that they are confined to the west and north shores of the lake and this may be an indication of the prevailing direction of the wind at the time of eruption.

(ii) *Salawa District.*

Near Salawa waterhole, about 5½ miles north of Loruk, there are extensive lava plains which decline gently northwards. Two miles north of Salawa a stream cuts into the plain, exposing coarse yellow tuffs dipping 3° E., while to the west there is a low lava fault-scarp which is probably the northern continuation of the fault which runs from point 3607 through 3404 and 3366 of the GS.GS. map. The altitude of these yellow tuffs is about 3,000 feet and they are therefore some 300 feet below the present level of Lake Baringo, or 800 feet below the maximum of " Lake Kamasia ".

This brings out the problem of the northern shore of the old " Lake Kamasia ", which was a continual source of speculation while in the field. From the vicinity of Adioget-Abalom the Kogore valley declines continuously northward for about 100 miles to Lake Sugota, south of Lake Rudolf. It is therefore difficult to see how Lake Kamasia was contained to the north. The " Barrier Range ", south of Lake Rudolf, is only 3,000 feet high, while the overflow of that lake into the Nile system was at little more than 1,600 feet. Besides this, the Loriyu plateau, to the east of Lake Suguta, is also only 3,000 feet, and could not have contained Lake Kamasia at 3,800 feet. It is therefore clear that some other barrier existed which has since been destroyed.

At first it was thought that such a barrier might have existed at Kinyang, but it was not until we reached Karpeddo that we reached a point where such a barrier could have stood.

(iii) *The Kinyang–Karpeddo Area.*

To the west of Kinyang the sediments continue at approximately the same altitude of 3,800 feet, as already seen elsewhere. There they were visited by Dr. MacInnes, who crossed the Burususwa River and continued westward over flat country till he reached a series of three lava fault-ridges. The most westerly of these was capped with an olivine-basalt (74*a*), but its base was formed of a series of sediments. Immediately below the basalt came a diatomite (74*b*) and beneath that a series of yellow tuffs (74*c*, 74*d*). These sediments he described as typical of the deposits of Lake Kamasia, which we had seen in the Baringo basin itself.

Later, when standing on hill 3240, the sediments were seen to extend northward in the direction of the Kito Pass, where they appeared from the distance to dip S.W. All of them seemed to be capped by lavas,

In the re-entrant of the Kito Pass a striking white conical hill capped with lava stands up from the floor of the valley. This proved to be composed of a series of stratified yellowish tuffs dipping gently W.S.W. and overlain by a phonolitic-trachyte (91*a*). Thus, the sediments of the Kamasian lake extend as far north as this point, though here almost entirely composed of volcanic material.

Kinyang Hill itself is the highest of a small group of hills, of which the form is governed by N.–S. and N. 15° E. faulting. The N.W. side of the range is composed of a thick series of pumice beds interbedded with thin sandy and earthy horizons which show local falsebedding. These tuffs are overlain by the Kenya-type phonolite (71*a*), which has similar characters to (91*a*) of the Kito Pass. The whole series dips south at 6°.

At the foot of hill 2750, N.W. of Kinyang, a series of lake beds are banked against the eroded tuffs. These contain innumerable rolled boulders and some " kunkar ", while the whole surface is littered with worked flakes, which appear to represent a Neolithic culture. Similar lake beds containing much volcanic material also occur, lying like a blanket along the foot of the hills to west of the valley (Plate IX, fig. 1).

From the above, it seems that the earlier tuffs of Kinyang Hill may be the faulted representatives of the Kamasian lake beds capped, as often seen elsewhere, by Kenya-type phonolite. The N.–S. faulting, so consistent throughout this area, seems, therefore, to have given rise to the Kinyang Hills at the same time as it broke down the barrier which, we shall see later, existed at Karpeddo, thus emptying the original Lake Kamasia when it stood at or about its maximum height. There followed an explosive phase from the Silali–Muruesse volcanic group which dammed up the fault valley sufficiently to permit the formation of a second shallow lake in which Kinyang must have stood as an island. On Kinyang itself this explosive phase is represented by a series of sub-aerially deposited yellow pumiceous tuffs which lie unconformably on the eroded surface of the Kamasian lake tuffs, and slope southwards at an angle of 40°.

It will be convenient to call this late Pleistocene lake " Lake Kinyang ". In it were deposited a series of sandy clays with much " kunkar " which are well seen in an area two miles N.N.W. of Kinyang village. Throughout these lake beds are found numerous boulders of a pink granite (75*a*) which probably originated as ejected blocks since no exposure of the Basement complex is known in any of the surrounding hills. The general level of these deposits in this area is 2,785 feet, but the highest beaches were observed at 2,840 feet.

North of Kinyang the N.–S. faulting continues, giving rise to a number of low features with downthrow always to the west. These faults disappear beneath the late yellow pumiceous tuffs which extend

all the way to Karpeddo. At Karpeddo the headwaters of the Kiprebo-Kodogo has cut back into the tuffs, forming a sheer-sided gorge in which a water-table is exposed in the lower few feet.

At Karpeddo the general level of the rift floor into which the Kiprebo-Kidogo cuts stands at little more than 2,500 feet, or some 1,300 feet below the level required to contain Lake Kamasia. Nevertheless, it seems that here was the site of the old volcanic barrier, for it is here that the valley is at its narrowest, with the great volcanic mass of Silali standing on the east while the deposits of Lake Kamasia, on the west, have merged into purely volcanic material of subaerial origin. I believe that this barrier was a wide mass filling the pre-existing rift, and that faults contemporary with those which destroyed it are to be seen at the foot of the east flank of the Tiati range, the remainder being buried beneath later lavas and ashes. Though it has been reported that Tiati itself is formed of Basement Complex rocks, none but volcanics were visible from a distance on the east side of the range. Unfortunately, it was not possible to examine the range in detail, but a visit was paid to it by way of the Kiprebo Kidogo valley, which begins in the Tiati scarps. There the river has cut a steep-sided gorge into the tuffs which form the foot-hills of the range. Here, too, were numerous boulders of Basement Complex rocks (e.g. 88*a*) which appeared to be derived from the tuffs in which they occurred as ejected blocks. Near the head of the valley the top of a conical hill was capped by a hard green trachytic tuff (89*b*), while near by a soda-trachyte (89*a*) was overlain by a thick mass of unconformable yellow tuffs of at least two ages. Glassy rocks similar to these trachytes are found at the foot of Karau (102*a*) and Goymonange (103*b*), both at the S.E. of Baringo.

A Kenya-type phonolite (83*a*) which has flowed round the epigenetic crater of Gesamoch on Silali is an almost identical rock with (91*a*) from the conical hill in the Kito Pass on the opposite side of the rift, though the former is clearly far younger. Though there is no visible nephelene in either of these rocks, they are otherwise extremely similar to some of the Kenya-type phonolites associated with the Kamasian sediments as, for instance, (71*a*) from Kinyang.

A series of minor faults with downthrow to the W., which disappear under the S.W. flank of Silali, are evidently the local expression of the faulting which destroyed the trans-rift barrier already referred to.

(iv) *Summary of Area North of Baringo.*

Since the Kamasian lake deposits extend far to the north of the present Lake Baringo basin, it is clear that the lake of that time must have been contained to the north by a barrier which no longer exists. This is considered to have existed in the Karpeddo area, where the floor of the rift was not downfaulted to the same degree as elsewhere,

or, more probably, where the barrier had been built up by extensive volcanics. That considerable volcanicity accompanied the rising Lake Kamasia is clear from the quantity of volcanic material included in the lake beds.

Extensive faulting occurred when Lake Kamasia was at or about its maximum of 3,800 feet, and this is considered to have broken down the northern barrier and allowed the lake to drain into the Suguta valley.

After this draining of the lake further volcanicity from Silali and associated centres once more built up the Karpeddo barrier sufficiently to allow the formation of "Lake Kinyang", while the equivalent eruptions from Korossa built the Adioget-Abalom barrier and permitted Lake Baringo to rise to 3,575 feet.

The Kinyang lake was in its turn drained by the back cutting of the Kiprebo-Kidogo, possibly aided by the access of water from Baringo, when the Adioget-Abalom barrier was broken down by the later N. 15° E. and N.W.–S.E. fault groups.

C. The Area East and South of Lake Baringo

East of Adioget-Abalom the southern lavas of Korossa have been fractured by the N. 15° E. faulting, and numerous cinder cones have formed along the line of the faults. A noteworthy example is the Logurdogi scarp (direction N. 11° E. : throw 80 feet) which cuts through an olivine-basalt (97*a*) and is straddled by at least one consequent cinder cone (Plate X, fig. 2). East of Logurdogi but west of the Kyamotting river there are numerous fractures downthrowing to east or west which affect the lower slopes of Korossa and are associated with small cinder cones. The most easterly members of this fault-swarm run north through Chebchuk to disappear under the slopes of Pakka. The two large fault-scarps west of Ol Doinyo Lengere are doubtless the northern expression of the same zone of fractures, but to the south the faulting dies out or is hidden beneath the alluvium of Baringo.

The main escarpment of this series, over which fall the Kyamotting and Mukutan rivers, is continued by the great cliffs of Karau, which itself appears to be an eruptive centre (the highest point is apparently an ash cone, though we could not visit it) modified by both N.–S. and N. 15° E. faulting. South-west of Karau, fractures of the latter trend are continued by minor scarps, of which the Goymonange fault is the most westerly visible. Numerous other small faults also associated with cinder cones carry on the fracture zone into the higher country east of Lorok at the south end of the lake, where they link with the major fault which runs north from the east side of Lake Hannington.

North of Morillo the plateau between Karau and the old Baringo Post stretches as far north as Terrterr, and is undoubtedly a fault block let down along the major rift fracture that here stretches

from the latitude of the southern end of Baringo Lake to Ol Doinyo Lengere.

At our camp near point 3480, by the Kyamotting river, the general altitude was about 3,500 feet, and the plains were strewn with gravels capping deposits whose true nature was largely obscured. What could be seen of the latter showed them to be pink clayey deposits which I was inclined to correlate with the early deposits of Lake Kamasia, on the west of the lake, but on following up the Kyamotting river I found a valley filling which appeared to be of lacustrine origin up to an altitude of 3,575 feet. Both in the Kyamotting valley and in the valley west of point 3450, where it also occurs, this deposit has been cut into by the present streams and now forms a narrow bench of red material bearing a remarkable fringe of huge scree boulders derived from the lava fault scarps.

This valley filling being clearly of post N. 15° E. faulting age, it appears that the lake remained at or just below 3,575 feet for some time after this faulting began. The altitude of this deposit compares reasonably with that of 3,625 feet, at which the unconformable deposits with a shelly band appear above the Red Bed in the Kapthurin district (p. 8) on the west of the lake. These deposits, together with others yet to be referred to, in the southern part of the basin represent a rise of the lake in the late Pleistocene which is probably comparable with the Makalian wet phase recognized by Leakey elsewhere in Kenya.

Later, a reduction of the lake level by the westerly extension of the N. 15° E. faulting, together with local N.W.–S.E. fractures at Adioget-Abalom, also assisted by increasing aridity, caused rejuvenation in the Kyamotting, Mukutan, and other valleys, with the consequent erosion of a large part of the valley filling, a process which still continues. A fine example of a perched block caused by this erosion is shown in Plate X, fig. 1, from the Kyamotting valley.

If the above interpretation is correct the equivalents of the Kamasian deposits on the west of the lake are not seen in this area. I am inclined to think that such deposits may be found in the plateau region between Baringo Post–Ol Doinyo Lengere scarp and the Karau Chebchuk fault zone. This plateau is bounded on the east by the 3,800 ft. contour and may, therefore, have been beneath the waters of Lake Kamasia at the time of its greatest extension. Should this be so it is possible that the Mukutan never did flow north through the Kommoll valley, as suggested by Gregory (1921, p. 109), but discharged direct into Lake Kamasia near the foot of the eastern escarpment. In such circumstances, when the N. 15° E. faulting gave the Baringo basin its present form, the Mukutan would naturally extend its course across the flats until it reached the new scarp over which it still flows to-day.

This is to some extent supported by the small size of the Kogore

valley after it has been joined by the Kommoll, which suggests that in time past there was no great volume of water flowing through it. On the other hand any deep valley which may have existed could have been obliterated by the subsequent extrusion of volcanic material.

At the time of our visit (February) it was possible to cross the swampy area south of point 3290 and pass between Lodungoro and Karau. In this area a number of low-lying ridges of lava indicate that the Korossa fault-swarm extends southward across this area, but the fractures are largely obscured by alluvium.

Half a mile west of the Karau scarp is a hill formed of trachytic tuffs (102*a*) which curve over steeply to the west. This, remarkably enough, appears to be a small local fold. Three miles further south similar tuffs (103*a*) but of a more consolidated nature have been cut by a fault with a throw of approximately 50 feet, running N. 20° E. The beds on the east of the fault dip beneath the alluvium at an angle of 40°. It was not possible to determine the significance of the structure or the age of the tuffs, but they are recorded for future reference, as they are an unusual rock for the area and appear to be of a greater age than the majority of the volcanics. They most resemble the trachytic types from west of Karpeddo (89*a* and 89*b*).

Another exposure of a related lava is the soda-trachyte (103*b*) of Goymonange ridge, at the southern edge of the lake. The northern face of this hill is cut across by a fault running N. 40° E., and the similarity of the lava to (102*a*) and (103*a*) suggests that here, beneath the alluvium, is a wide area of these apparently older trachytic rocks.

At the ford of the Ol Arabel (Nanyokye) River, and about 100 yards up stream, a river bank section exposes water-bearing sands overlain by red clays. The clays are themselves unconformably overlain by some 6 feet of gravel with sandy lenses. At the north end of the section both these deposits are truncated, and banked against them is a later series of alluvial deposits. It was not possible positively to identify the age of these beds, but I regard the lower series as belonging to the early Kamasian lake rise. The unconformity would then represent the first draining of the lake basin and the upper gravels the early deposits of the subsequent lake rise. The later alluvial deposits are of comparatively recent age and are presumably to be related to the 25 ft. and lower beach levels observed around the south-east shores. These beaches clearly indicate changes in precipitation over the area. Though no evidence was observed upon which the relative ages of these lower beaches could be determined it seems certain that the lake has dried out entirely at least once since the present overflow level was established at Adioget-Abalom because the molluscan fauna, *Melanoides tuberculata* (Müller), *Corbicula consobrina* (Caillaud), and *C. africana* (Krauss) and *Unio* sp., found in the deposits of the second major lake rise do

not now inhabit the lake (Fuchs, 1934, p. 104). Since the maximum depth of the lake (1930) is only 20 feet, this does not seem improbable, and it probably occurred at the end of Makalian wet phase recognized elsewhere in the area.

The most southerly point of the Baringo basin is to be found in the headwaters of the Bogoria River, some distance south of the southern end of Lake Hannington.

The N.–S. system of faults described S.E. of Marigat (p. 158) extends to this area, and it is these faults which have formed the Bogoria swamp and the Bogoria River valley. It would be expected, therefore, that the deposits found in the fault valley re-entrants near Marigat would also be found here, but the general level of the country declines eastwards, so that the faults here form valleys some 300–400 feet lower than near Marigat. Thus, though these valleys do contain lake beds they belong to the 3,575 ft. lake. These deposits include sands and gravels which contain freshwater mollusca and some kunkar, and were observed to an altitude of 3,500 feet. Where the base of these deposits was seen they rested upon representatives of the analcitic-phonolites which form the surrounding lava ridges (e.g. 108*a* from the N. nose of hill 3830 ; 109*a* from the top of the scarp of hill 3830). In the upper part of the beds a fine-grained gravel cemented with a ferruginous matrix was noticeable. This gravel is almost identical with the ferruginous deposit capping the lake deposits mentioned south of Lorok, which together with a similar molluscan fauna to that found in those deposits suggest that these sediments also belong to the 3,575 ft. lake rise (? Makalian). Here it may be recorded that a large quantity of hot water (100° F.) flows into the Bogoria swamp from springs associated with a N.–S. fault west of the Bogoria River and N.W. of point 3830.

From this area southwards the entire country is broken up by a series of N.–S. faults having steep scarps to the west and long dip slopes to the east. The Bogoria river, which flows in one of these valleys, draws the greater part of its water from the " Hot Springs " due west of Lake Hannington. There, at an altitude of 3,800 feet, a series of phonolites and tuffs (113*a–d*, 114*a*, 115*a–d*) is interbedded with reddened lacustrine clays with gravel lenses. All these deposits have been faulted and in part covered by 10–30 feet of calcareous tufa from the volcanic springs.

The whole succession of lavas, tuffs, and aqueous deposits is so complicated that it was impossible to elucidate their history in the few hours available. It is nevertheless clear that at a time of considerable volcanic activity lake deposits were being formed during periods of quiescence, and it seems certain that these are the southern representatives of the Kamasian lacustrine deposits so widespread to the west and north of Lake Baringo.

Final Summary and Conclusions.

On palaeontological evidence the Kamasian deposits of Gregory (1921, p. 114) are shown to be of Middle and Upper Pleistocene age, and not Miocene as suggested by Gregory.

It is considered that the early fossiliferous deposits were formed shortly before a time when the lake dried up completely, but conditions soon altered and the lake began to rise again, attaining to a maximum height of about 3,800 feet. During the greater part of this lake rise there was considerable volcanic activity, which gave great thicknesses of ashes and tuffs besides successive lavas ranging from olivine-free basalts through analcitic and Kenya-type phonolites to a series of olivine-basalts. Shortly before the lake attained its maximum there was a period of comparative volcanic quiescence when extensive diatomites were formed along the western margin of the lake.

It is believed that the northern end of Lake Kamasia lay in the vicinity of Karpeddo, some 32 miles north of the present lake. The barrier that there contained the lake within the rift valley was formed of material ejected by the early activity of Silali and its associated eruptive centres, possibly based upon a higher fault block of the rift floor.

After some fluctuation of the lake, due either to minor faulting or climatic variation, this barrier was broken down by N.–S. faulting, with consequent draining of the lake. Renewed volcanic activity built up a second barrier, this time in the vicinity of Adioget-Abalom, near the present north shore of the lake. This permitted a new lake rise in a much reduced basin. In this lake a second series of lake beds formed, together with valley fillings which occur up to a height of 3,575 feet.

At the time when the eruptions of Korossa were forming this barrier, the barrier in the Karpeddo region was replaced by material emanating from Silali and perhaps Pakka. This latter barrier was lower than the earlier one but permitted the formation of a shallow lake to the north of the present Lake Baringo basin, which has been called " Lake Kinyang ". In this a series of apparently unfossiliferous sediments was formed, but the presence of large numbers of worked flakes which appear to belong to one of the Neolithic cultures, suggests that man of that time lived around its shores and is indicative of its late Upper Pleistocene age.

It seems likely that the breakdown of the second Karpeddo barrier was due to the overflow of the Kinyang lake, possibly consequent upon the destruction of the Adioget-Abalom barrier by faulting and the inflow of a huge quantity of water from the southern lake, but faulting may here also have been a contributory factor. The sequence of events described is shown diagrammatically in Text-fig. 7.

From these events it is clear that the Baringo basin is not a good

index of pluvial fluctuation. Indeed, it is hard to show whether any particular rise or fall of the lake was due to climatic change, faulting, volcanic barrier building, or a combination of one or more of these factors. Here, in fact, is a lake which at first sight offers evidence of pluvial variation, but which, as suggested by Zeuner (1945, p. 214), is liable to be highly misleading. So much is this so that were it not for the fact that the Baringo basin clearly could not have contained the lakes it did, unless volcanics and earth-movement had played their part, an examination of the lake beds alone would appear to provide evidence for successive pluvials due to changes of precipitation. Thus it might be considered that the 3,800 ft. level, with its fluctuations while near the maximum, is equivalent to the Gamblian of other lake basins ; and that the later lake beds at the 3,575 ft. level are equivalent to the Makalian.

Though it seems likely that these equations may be true with regard to time, the causes of the changing lake levels were, in fact, different to those of other lakes, and it is necessary to emphasize that there is as yet no local evidence which can be used to equate the Baringo fluctuations with those of other East African lakes with certainty. Thus, with the knowledge that all these fluctuations occurred after the Middle Pleistocene there is still a variety of ways in which the Baringo fluctuations can be equated with the pluvial sequence worked out elsewhere.

One is therefore inclined to look with suspicion at other lake basins of East Africa where volcanics might have played a similar role. It may be argued with reason that the evidence for the pluvials is too universal for it to be dismissed on these grounds. Even so, there are other basins where lake fluctuation has been caused by earth-movement and volcanics ; for instance, in Lake Rudolf faulting lowered the level of the lake floor at the end of the Lower Pleistocene (Fuchs, 1939, p. 251), and it may also be assumed that the formation of the Barrier Range at the south end of Rudolf, in the Upper Pleistocene, reduced the area of the lake sufficiently to allow the available inflow from the rivers to raise the lake level and form the 220 ft. beaches.

Though it is not suggested that the rise of all East African lakes is the direct result of barrier building or tectonic effect, it does seem likely that there is some relationship between them and that the true cause of pluviation may be found in the periodical effect of volcanicity on meteorological conditions (Fuchs and Paterson, 1947).

Appendix

The Volcanic Succession.

The volcanic series is chiefly composed of basalts and phonolites, together with a few trachytic forms. The succession appears to be as follows :—

4. Olivine-basalts.
3. Kenya-type phonolites.
2. Analcitic-phonolites.
1. Olivine poor basalts.

Basalts.

There appear to be two groups of basalts, the earlier being poor in olivine, the later olivine-rich. Rocks of the earlier type occur below the Red Bed at Kapthurin (*7a* and *33c*), just east and below point 4,300 feet, S.W. of Marigat (*57a*), and in the Tiggeri River, ¼ mile S.S.W. of Marigat (*55c* and *55d*). In the last case they are overlain by a trachyte (*55a*). A further example of this type of basalt is (*37a*) from the Second Marigat Gorge. This rock lies immediately above a phonolite (*36a*), but the latter is probably a dyke which may cut through (*37a*) to the surface.

In these olivine poor basalts plagioclase phenocrysts are abundant. In (*7a*) the feldspar is labradorite-bytownite, the groundmass consisting of feldspar laths giving low extinction angles with augite grains and abundant cubes and blades of iron ore.

Dr. Campbell Smith states : " A porphyritic feldspar basalt resembling some of the above (olivine poor types) was collected by A. M. Champion from the Loriyu plateau between the Baringo basin and Lake Rudolf (Campbell Smith, 1938, p. 527, no. 113). This was associated with olivine-basalts which resemble those now found in the Baringo basin. It may therefore be that both forms of basalt belong to the one series, the Laikipian basalts. However, in some respects the porphyritic feldspar-basalts have characters which accord fairly well (as far as can be judged from the published description) with the Samburu basalts occurring below the phonolites in the district described by Shackleton (1946, p. 30). One might also compare these rocks with Shand's Kijabe basalt (Shand, 1936, p. 310), but this carries phenocrysts of olivine as well as plagioclase."

Apart from the above petrological considerations the field relations show that these basalts are earlier than the olivine-rich forms, for they underlie either lake beds or phonolites, both of which are frequently seen to underlie the olivine-rich basalts. It is, however, uncertain whether these olivine-poor types are older than all the phonolites or only the Kenya-type phonolites.

Referring to the olivine-basalts, Dr. Campbell Smith says : " Of the olivine-basalts some carry micro-phenocrysts of plagioclase, augite, and olivine, others have abundant phenocrysts of olivine and fewer of plagioclase and augite. Several have interstices filled with a colourless mineral which may prove to be analcime. They seem similar to the Laikipian basalts briefly described by Shackleton (1946) and are even

more like the rocks described by Campbell Smith (1938, p. 527) from the Loriyu plateau."

These rocks are widespread, for they extend southward from the Loriyu plateau through Karpeddo (Koloruk (81*c*), Kapturnet (81*b*)) to the Kinyang area (66*a*, 74*a*, 76*a*), and thence to the north end of Baringo (63*a*, 93*a*). West of the lake they are represented by (52*a*) in the Nasagum area, and on the east of the lake by (97*a*) from the Logurdogi scarp.

Phonolites.

Most of the phonolites are variations of the Kenya-type described by Campbell Smith (1931, pp. 229–236) and may be equivalent to Shackleton's Losiolo phonolites (1946, p. 34). The widespread nature of these Kenya-type phonolites is shown by their occurrence from the Kinyang area (71*a*, 73*a*, 74*a*), southward through Salawa (92*a*), Loruk (95*a*, 96*a*), to Kapthurin (11*a*, 7*b*, 32*a*). These phonolites are certainly later than the olivine-poor basalts, and except for one case at Kapthurin where a phonolite (7*b*) may overlie an olivine-basalt (8*a*), are probably older than the olivine-basalts. To the south from Nasagum, through Marigat to the Hannington area, another type of phonolite is prevalent which, from its field relationships, appears earlier than the Kenya-type. These earlier phonolites have been stated by Dr. Campbell Smith to be "characterized by much interstitial analcime filling interstices between very thin and sometimes curved feldspar laths, which are dispersed in divergent and sometimes radial groups so that they enclose well-defined triangular areas". These rocks occur underlying lake sediments in the Nasagum valley (49*a*), or are for other reasons plainly earlier than the lake sediments as, for instance, to the west of Marigat (44*a* and 42*b*) and east of Marigat (40*a*), where they form scarps of earlier age than the lake sediments. These, together with other specimens of similar type (e.g. 40*b*, 35*a*, 5*b*, 4*a*) which occur low in the series, indicate that the two main groups of phonolites are of different ages.

In the Lake Hannington area both types of phonolite occur, but the true Kenya-types are clearly later than those rich in analcime, which appear to form the base upon which the former have been poured out prior to the faulting which affected both series. With the earlier group it is suitable to associate the glassy rocks having neither analcime nor nepheline, such as (89*a* and 89*b*) from west of Karpeddo, (102*a* and 103*a*) from near the west foot of Karau, (103*b*) from Goymonange, although they cannot definitely be dated, for they fit well into the sequence with (35*a*) from the Marigat area, and (107*a*, 108*a*, 109*a*) from the Hannington district, to show a transition in type, as suggested by Dr. Campbell Smith, from those with little or no analcime and

nepheline through forms with much interstitial analcime to the true Kenya-type phonolite with abundant nepheline, this last being the youngest of the series.

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EXPLANATION OF PLATES

PLATE IX

FIG. 1.—Deposits of " Lake Kinyang " blanketing lavas and tuffs of the Rift Valley floor.

FIG. 2.—Marigat Gorge cut through phonolitic and trachytic flows.

FIG. 3.—Typical " Kamasian " sediments in the Nasagum valley.

PLATE X

FIG. 1.—Earth pillar showing erosion of valley filling in Kyamotting Valley.

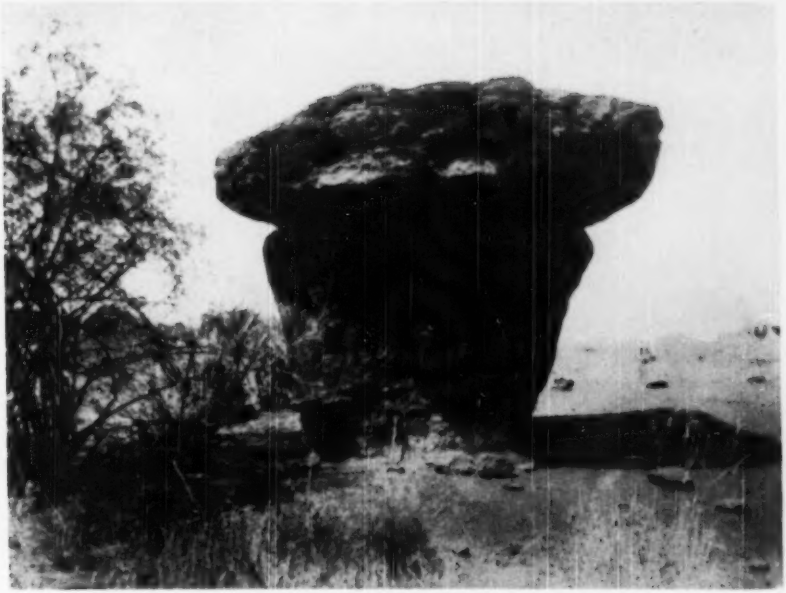
FIG. 2.—Volcanic cones associated with Logurdogi fault scarp in olivine basalts.

Note.—It is hoped that besides illustrating the text, these photographs will assist future travellers in identifying the positions from which the evidence is taken.

PLATE XI

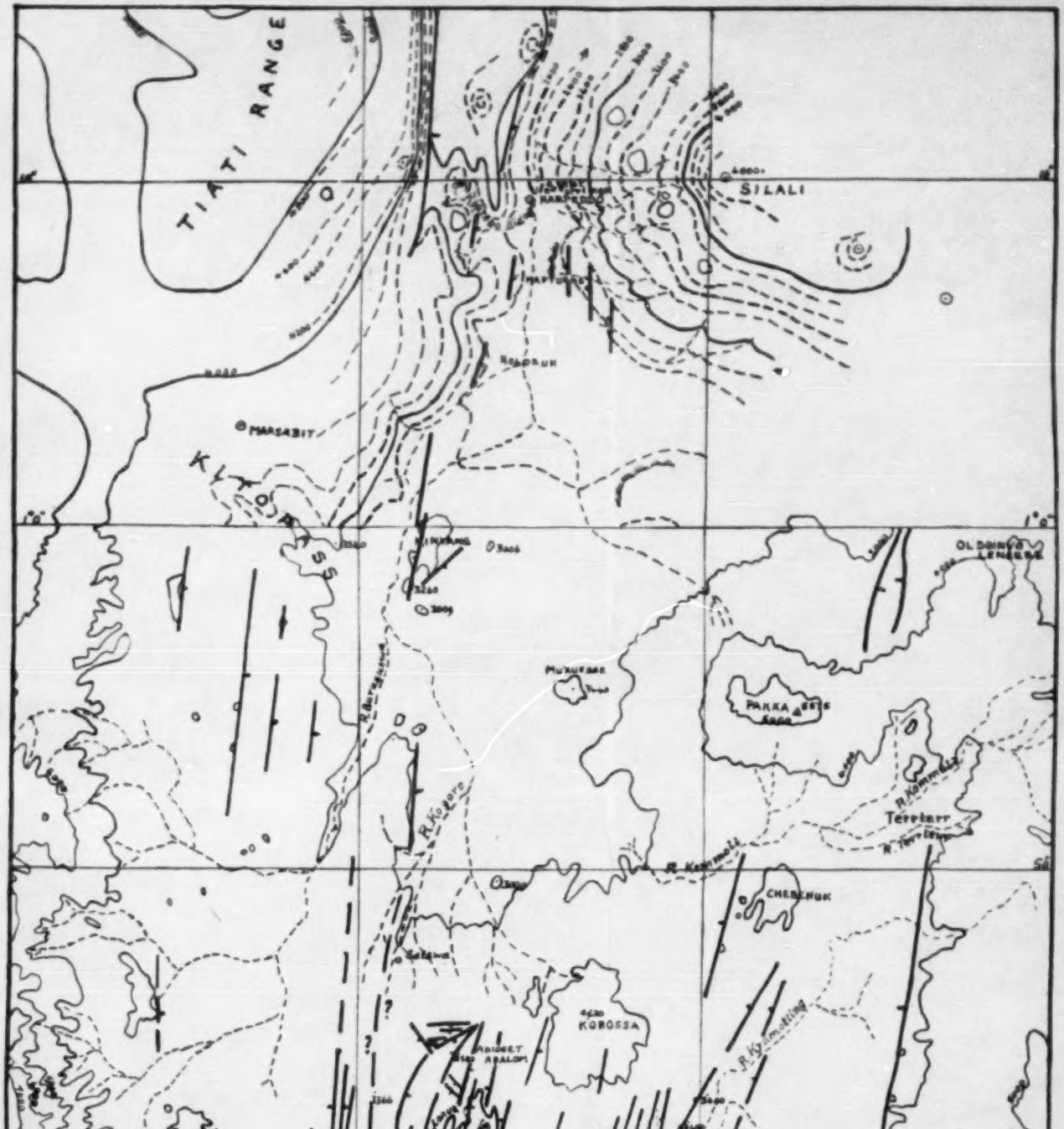
Map of the Baringo Basin on the scale of 5 miles to 1 inch.

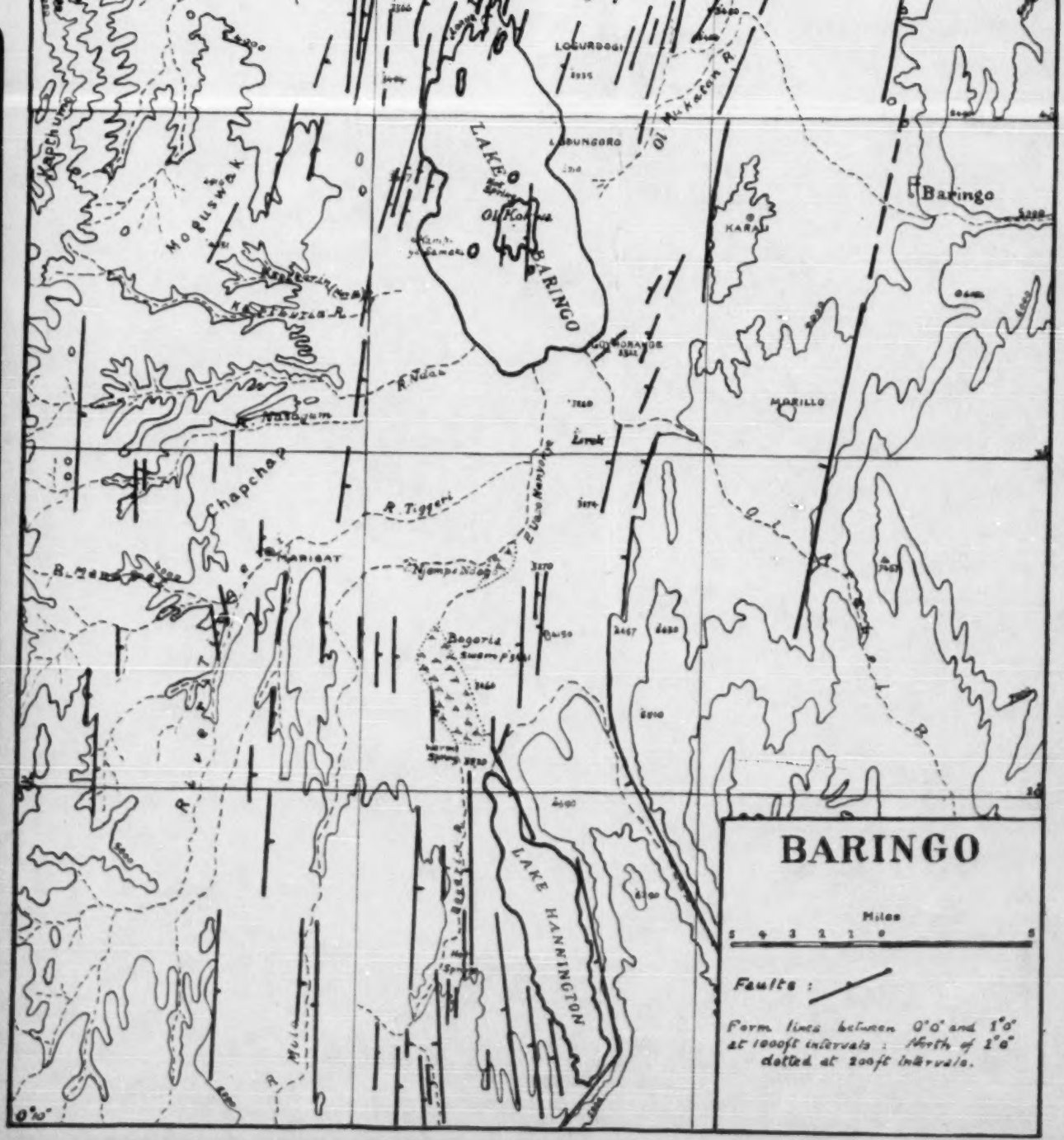
PLEISTOCENE EXPOSURES IN THE BARINGO BASIN.

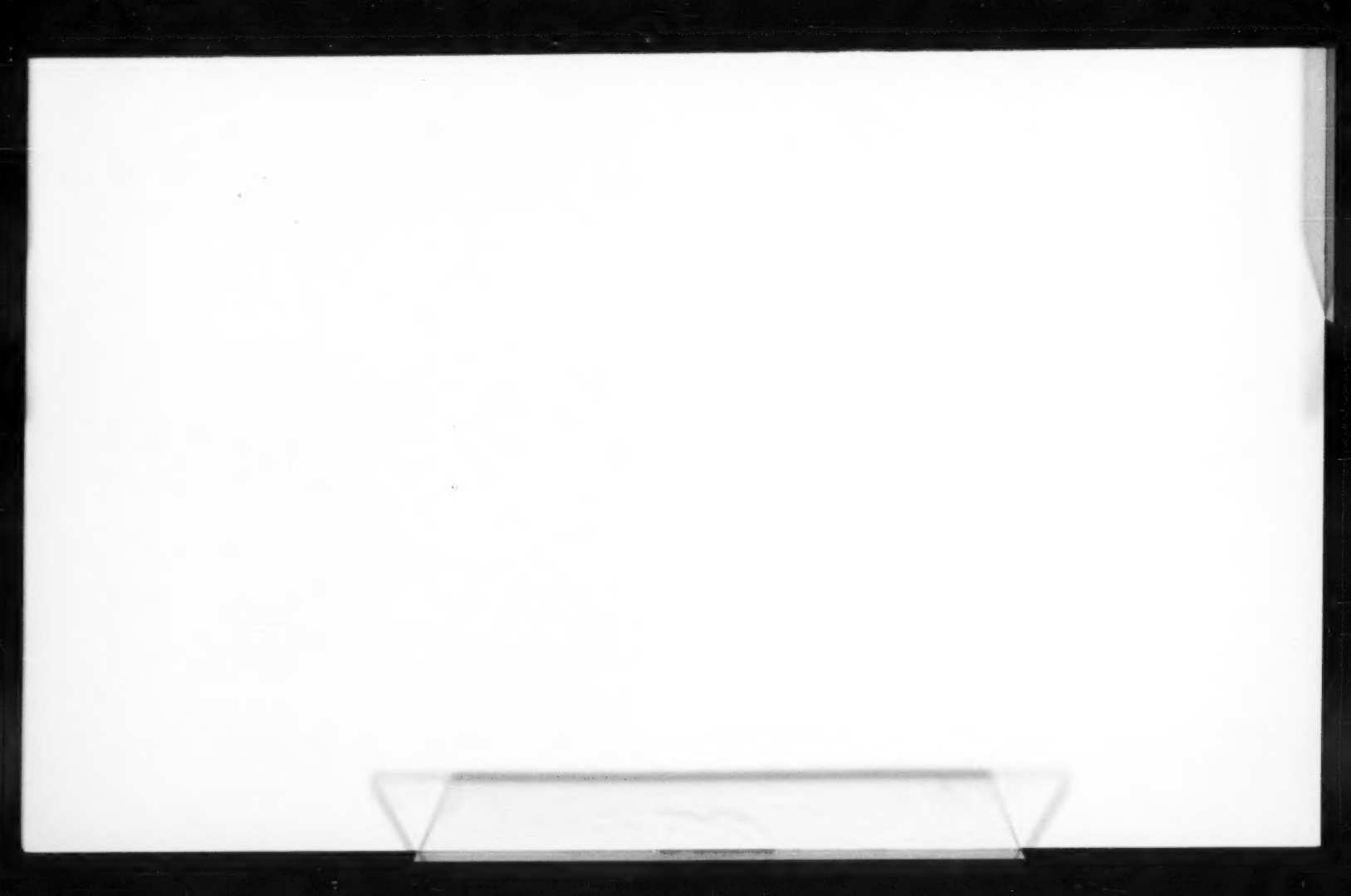


EARTH PILLAR, KYAMOTTING VALLEY.

LOGURDOGI FAULT SCARP.


TIATI RANGE
SILALI
MARSABIT
KLITO
OL DONYO LENGAI
PAKKA
TEPTERR
CHERCHUK
KOROSSA


BARINGO
Miles
5 4 3 2 1 0 5
Faults :
Form lines between 0'0" and 1'0" at 1000ft intervals : North of 1'0" dotted at 200ft intervals.
LAKE HANNINGTON
LAKE BARINGO
Baringo
KARAU
MORILLO
LOGURDOGI
LABUNGORO
Ol Kokwa
Ol Mekelon R.
Mobuswak
Chapchap
R. Tigeri
R. Molo
R. Ndau
R. Mukutan
Nyampkoi
Bogoria
Lorok
Kabarnet
Marigat



Note on the Depth and Temperature of the Gault Sea as indicated by Foraminifera

By M. H. KHAN

ABSTRACT

Foraminiferal evidence in the past has been held to suggest that the Gault is a deep sea deposit—a view which conflicts with the belief held by many on geological and other palaeontological grounds that the Gault was laid down in fairly shallow water. This contradiction is due to a misinterpretation of the foraminiferal evidence which, in the opinion of the writer, favours a temperate, relatively shallow marine environment for the deposition of the Gault, at least in South-East of England.

CONFLICTING views have been expressed in the past regarding the probable depth at which the Gault was deposited. Price (1875), on the molluscan evidence, deduced 100 fathoms or even less. He thought that the Gault had been laid down in a gradually sinking area and that the sea in Upper Gault times was deeper as compared with that of the Lower. Jukes-Browne (1900, pp. 413–15), by using only the Lamellibranchs, calculated a depth of 150 to 180 fathoms for the Lower and 200 for the Upper Gault. That the Gault has been deposited in shallow water is not only indicated by its molluscan fauna but also by geological evidence such as the presence of nodular phosphatic beds, and this view has been accepted by all who have worked in this area. Spath (1943, p. 758) remarks that the Upper Albian sea may have been 100 fathoms deep and that there was no deepening of the sea in Upper Gault times as was supposed earlier by Price ; for, as the former says, " even the glauconitic seam of bed XII at Folkestone indicates the temporary influence of current action, and the Chloritic Marl rests on an eroded surface of bed XIII."

Chapman (1898), on the other hand, from foraminiferal evidence, suggested a much greater depth for the deposition of the Gault than has been deduced or considered feasible from all other sources of evidence. He calculated the depth of each bed by choosing certain species of foraminifera which are known from Recent deposits, and working out an average depth for each from the records of its present-day distribution. By this means he arrived at 830 fathoms for the Lower and 860 fathoms for the Upper Gault.

These figures are misleading and in the present writer's opinion there is little evidence from the foraminiferal fauna to suggest that the Gault is a deep-sea deposit. An examination of the data regarding the bathymetric ranges of those Gault species which are still found in the oceans to-day shows that they are cosmopolitan in their distribution and occur from less than 100 fathoms to very great depths. The complete absence of exclusively deep-sea forms and the fact that all

without exception have been recorded from less than 100 fathoms clearly indicate that a shallow sea was probable. But owing to the very wide bathymetric range of these species, a depth estimated merely from their average ranges, which also includes the records of their deep-water occurrences, would not only suggest a high but even an abyssal depth. Bearing in mind that all evidence, including that of foraminifera, favours a shallow sea, the only possible way of estimating depth from such cosmopolitan forms is to ignore in the calculation of average depths of species the record of their occurrences beyond 1,000 fathoms, as suggested by Jukes-Browne.

Average depths for each species given in Table 1 have been calculated here by taking into consideration only those bathymetric records at which a species was found to occur most commonly, rare occurrences beyond 1,000 fathoms being excluded. With the exception of *Glomospira charoides* (Parker and Jones), *Haplophragmoides latidorsatum* (Bornemann), and *Ammobaculites agglutinans* (d'Orbigny) the records for all species from depths of less than 1,000 fathoms were found to be more numerous than those of deep water. Each work consulted for the bathymetric ranges gave a complete record of the depth and the number of stations at which a particular species was recorded together with its frequency. From these the average depth of any species can more accurately be estimated than from the minimum and maximum ranges given in most of the earlier publications of the deep-sea expeditions. The mean of the total averages mentioned in column 7 of Table 1 comes to 183, suggesting about 180 fathoms as the probable depth of the Gault sea, which virtually confirms the opinion of Jukes-Browne (1900) on the evidence of lamellibranchs. The exact figure is of little importance, for if the average depths of species were computed by some other method a different figure would be obtained. Generally speaking, foraminifera are adapted to a wide range of habitat, and, in the absence of species of definite ecological value, evidence should be taken in conjunction with geological and other confirmatory evidence. That the depth of the Gault sea may have been even shallower has been suggested by some authors, and if this is indicated by other geological observations the foraminiferal evidence would not be contradictory.

Recent species, however, form only a small percentage of the total number known from the Gault, but from a comparison of the present-day habitats of those families and genera to which the others belong some additional information can be obtained.

The family Lagenidae, which supply the largest number of genera and species known from the Gault, has a wide bathymetric distribution. According to Cushman (1923, p. 3) the best development of this family is seen in tropical regions at depths of 100 to 500 fathoms. Norton

TABLE I.—AVERAGE BATHYMETRIC RANGES OF CERTAIN GAULT FORAMINIFERA BASED ON THEIR DISTRIBUTION IN RECENT SEAS

	Cushman, 1918–1931	Heron-Allen and Earland, 1914–15	Heron-Allen and Earland, 1916	Heron-Allen and Earland, 1922	Earland, 1933	Earland, 1934	Mean average depth in fathoms
1. *Ammodiscus incertus* d'Orbigny	525	—	35	276	—	332	292
2. *Ammodiscus tenius* Brady	—	6	—	284	—	—	145
3. *Glomospira charoides* (Jones and Parker)	—	—	28	—	—	458	243
4. *Glomospira gordialis* (Jones and Parker)	—	21	30	208	95	340	139
5. *Haplophragmoides glomeratum* (Brady)	—	—	32	447	135	330	243
6. *Haplophragmoides latidorsatum* (Bornemann)	—	—	—	432	—	—	432
7. *Ammobaculites agglutinans* (d'Orbigny)	553	23	—	—	—	648	408
8. *Dorothia filiformis* (Berthelin)	—	40	23	315	—	—	126
9. *Trochammina globigeriniformis* (Parker and Jones)	573	10	33	274	121	471	239
10. *Trochammina nana* Brady	117	—	—	—	—	334	225
11. *Robulus crepidula* (Fichtel and Moll)	158	—	27	310	124	187	161
12. *Lenticulina convergens* (Bornemann)	325	—	16	396	124	—	215
13. *Lenticulina gibba* (d'Orbigny)	416	—	27	273	—	248	241
14. *Lenticulina rotulata* Lamarck	252	10	23	150	164	—	120
15. *Marginulina glabra* d'Orbigny	—	—	16	162	—	—	89
16. *Dentalina communis* d'Orbigny	394	15	27	210	—	—	161

	Cushman, 1918–1931	Heron-Allen and Earland, 1914–15	Heron-Allen and Earland, 1916	Heron-Allen and Earland, 1922	Earland, 1933	Earland, 1934	Mean average depth in fathoms
17. *Dentalina consobrina* d'Orbigny	—	—	25	70	117	—	70
18. *Dentalina pauperata* d'Orbigny	288	—	50	228	113	268	189
19. *Nodosaria soluta* Reuss	—	—	—	70	—	—	70
20. *Nodosaria radicula* (Linn)	—	—	—	149	—	—	149
21. *Saracenaria italica* Defrance	204	—	—	70	—	—	137
22. *Lingulina carinata* d'Orbigny	—	40	3	92	—	—	45
23. *Lagena apiculata* (Reuss)	—	6	28	128	112	168	88
24. *Lagena hispida* Reuss	639	—	29	346	—	—	338
25. *Lagena sulcata* (Walker and Jacob)	—	42	25	208	92	194	112
26. *Gladulina laevigata* (d'Orbigny)	—	—	20	191	—	189	100
27. *Ramulina globulifera* Brady	—	—	—	219	—	—	219
28. *Bolivina textilaroides* Reuss	—	19	30	408	89	188	147
29. *Spirillina tuberculata* Brady	—	—	—	188	—	119	153
30. *Epistomina elegans* (d'Orbigny)	445	26	30	256	—	—	189
31. **Pleurostomella alternans* Schawager	—	—	—	—	—	—	189
32. **Anomalina ammonoides* (Reuss)	—	—	—	—	—	—	232

* Average depth for these species was calculated in similar way from other sources.

(1930, p. 368) found the members of this family common between 5 to 60 fathoms in Floridan and West Indian regions. The distribution of many genera of the Lagenidae seems to be controlled by temperature

rather than depth. Cushman (1930, p. 3) pointed out that *Lagena* attains a great development in shallow waters in certain temperate regions such as those around the British Isles, while in other regions it is found common at 1,000 to 2,000 fathoms. The genera *Robulus*, *Lenticulina*, *Vaginulina*, and *Saracenaria* are best developed in tropical regions from 100 to 500 fathoms, but at similar depths in cold waters there is a marked decrease in the number of species. Species of *Frondicularia* seem to be comparatively rare in the seas of the present day. According to Cushman (1923, pp. 139–140) a limited development of this genus is seen in the warm waters of the Western Atlantic and the warm and subtropical waters of the Pacific at depths between 100 and 500 fathoms.

The Rotaliidae and Anomalinidae, which follow the Lagenidae as the best represented families in the Gault, occur to-day " rather uniformly at nearly all depths and as families do not seem to possess any definite ecologic value " (Norton).

The Polymorphinidae have a wide bathymetric distribution in the Atlantic and Pacific oceans. Norton recorded all the genera and species of this family from the Floridan and West Indian regions from shallow waters.

The Buliminidae behave in the same way, and according to Norton (1930, p. 348) " are not restricted as regards conditions of depth and temperature ". One species of *Virgulina* (*V. punctata* d'Orb.) was found by Norton in 5½ to 16 fathoms. Of the thirteen species of the genus *Bolivina* recorded by Norton all, with the exception of four, occurred in shallow water. Cushman (1922, p. 29) states that the species of this genus for the most part seems to be very local in their distribution. One species of the genus *Siphogenerina* was recorded by Norton from 5½ and 8 fathoms. According to Cushman (1923, p. 173) this genus is best developed in tropical waters below 500 fathoms.

Of the arenaceous families represented in the Gault, the Textulariidae and Valvulinidae are found commonly in shallow waters to-day. Verneuilinidae show a wide bathymetric distribution, and according to Norton (1930, p. 337) " do not seem to be restricted to any particular ecologic zone ". The members of the families Ammodiscidae, Lituolidae, Reophacidae, and Trochamminidae seem to be more common in cool and deeper waters, although genera belonging to these families have been recorded from shallow waters by many authors.

There is thus nothing in the evidence from the present-day distribution of living species of the families represented in the Gault to suggest that it could not have been formed under shallow water conditions.

Data concerning the thermal distribution of the majority of the recent species considered earlier shows that they occur in the oceans of

to-day at temperatures ranging from 7·7° C. to 20·7° C., although one or two species suggest a still lower limit. Norton gives the maximum and minimum temperature range at the depths at which most of the families and genera represented in the Gault are common as between 21·5° C. to 31·4° C. and 18·9° C. to 24·8° C. From this it is suggested that the climatic conditions during the deposition of the Gault may have been more or less temperate.

Thus the evidence set forth here favours a temperate, relatively shallow marine environment for the deposition of the Gault.

ACKNOWLEDGMENTS

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The Diorites and Associated Rocks of the Glen Tilt Complex, Perthshire. II. Diorites and Appinites

By W. A. Deer

Abstract

The south-eastern margin of the Glen Tilt mass consists of a series of diorites showing a considerable variation in mineralogical and chemical composition. Associated with, and enclosed within, the diorites are a number of small masses of coarser hornblende-felspar rocks which are described as appinites. There is an absence of sharp contacts between the various rock types of the complex and a hybrid origin is suggested to account for the mineralogical assemblage of the appinites.

I. Introduction

THE greater part of the Glen Tilt complex consists of biotite and biotite-muscovite granites bounded on the south-west and south-east by an earlier series of intermediate and basic rocks. The intrusion of the biotite granite was accompanied by the formation of a series of acid and intermediate hybrid rocks, a description of which has been given (Deer, 1938*a*). In this paper the diorites and associated rocks of appinitic type of the Glen Tilt mass are described, a discussion of their formation will be given in a subsequent paper in which the form and origin of the complex as a whole are considered.

The diorites and associated appinitic rocks have an L-shaped outcrop, the base of which extends for approximately five miles in a north-easterly direction along the Tilt valley, along which these rocks occur in a narrow belt, a third to half a mile in width forming the steep northern slopes of the valley. At the south-western end of the complex the diorites extend in a north-westerly direction for three and a half miles, and occupy the high undulating tableland of Braigh na Creagan Breae and the Feith au Lochain.

Although on sheet 64 of the Geological Survey of Scotland, the whole of the diorites are undifferentiated, it is stated in the memoir (Barrow, Cunningham Craig, 1913) that the diorite "varies from a distinctly basic rock with good-sized crystals of hornblende (the rock described as the typical Glen Tilt diorite (Teall, 1888)) through tonalite to a lighter rock in which hornblende is present in small amount". Within the diorite area are a number of relatively large masses of granite and intermediate rocks, and the field relationships and composition of the latter show that they are hybrids similar to those previously described (Deer, 1938*a*). Within the considerable variation shown by the diorites a medium-grained quartz diorite is the commonest type, but no sharp contacts have been found between the diorites and the quartz- and quartz-mica diorites. The typical Glen Tilt diorite

of Teall is a coarse textured rock rich in amphiboles, one generation of which typically occurs as large phenocrysts. These rocks have a very limited distribution and occur as small masses usually less than fifty yards in diameter ; they are here described as appinites.

II. The Diorites

The diorites consist essentially of plagioclase and hornblende, and are medium-grained in texture. Atlhough some variation in the proportion of the two main constituents occurs they form a group distinguishable in the field from both the quartz diorite and the appinites. In thin section the rock consists of subhedral tabular felspar and hornblende. Quartz is typically absent but may occur as small interstitial grains. Biotite resulting from the alteration of the hornblende may also be present. The plagioclase is zoned from Ab_{40} ($\alpha' = 1{\cdot}559$) to Ab_{70} ($\alpha' = 1{\cdot}543$), and although crystallization of the felspar began earlier than the amphibole the latter shows a moderately well developed form. The hornblende has been separated and analysed (Table 3, No. 1) ; it is rich in ferrous iron, combines low silica with a moderate percentage of alumina, and has low Fe_2O_3/FeO and Na_2O/K_2O ratios. Pleochroism is from pale yellow to green with $\gamma = 1{\cdot}680$, $2V = 66°$, and $\gamma \wedge c = 15°$. Alteration to an antigorite with γ = deep green, α = pale yellow-green commonly occurs. Sphene and apatite are abundant accessories and together with magnetite occur in greater amount than in the appinites.

A typical diorite has been analysed (Table 1, No. 2). In chemical composition and mineralogy it is not unlike the medium appinitic diorite of Garabal Hill (Nockolds, 1941). The latter rock contains considerably more potash and has 10 per cent modal biotite, but apart from these features the two rocks are closely matched. Both rocks are poor in silica and rich in alumina, in which particulars only do they differ significantly in composition from the pyroxene mica diorites of the Garabal Hill and Arrochar complexes.

The main variation observed within the diorites is a slightly darker coloured rock finer in grain-size than the typical diorite and containing a higher percentage of ferromagnesian constituents. In this variety a clinopyroxene is usually present as small cores within the amphibole. Plagioclase Ab_{42} ($\alpha' = 1{\cdot}558$) occurs in hypidiomorphic plates. Two generations of amphibole are present ; one variety occurs in medium-sized crystals with $\gamma \wedge c = 15°$ and pleochroic from α = pale yellow to γ = light brown ; the other is pleochroic from α = pale yellow to γ = yellow-green and forms many small allotriomorphic grains enclosed in the plagioclase. The cores of pyroxene within the larger variety of amphibole, are pale green in colour with $\gamma \wedge c = 41°$; the accessories, magnetite and zircon, are not abundant. Compared

with the typical diorite, the basic composition and finer texture of this rock, together with the high percentage of pyroxene cores and the development of a second variety of hornblende within the plagioclase, suggests that it may be derived from the alteration of a more basic rock. It is also significant that as the adjacent typical diorites are approached the plagioclase becomes richer in the albite molecules

TABLE 1.—DIORITES AND QUARTZ-MICA DIORITES

	1.	A.	B.	2.	C.	D.	E.	3.	F.	4.
SiO_2	47·74	46·52	51·36	48·76	47·68	54·07	53·75	52·33	58·28	56·73
Al_2O_3	20·85	13·67	16·83	19·77	19·47	15·36	16·20	21·23	18·08	20·18
Fe_2O_3	2·25	1·92	1·39	1·83	2·76	0·98	0·83	3·54	1·84	2·15
FeO	6·14	8·11	7·72	7·81	6·28	6·76	7·42	4·93	4·06	3·60
MgO	8·33	13·18	4·80	4·28	6·44	6·44	6·55	2·67	3·57	2·05
CaO	10·36	9·06	8·30	7·94	8·02	8·09	7·90	6·98	5·14	5·69
Na_2O	1·70	1·23	3·40	3·40	3·38	3·54	3·25	3·01	4·02	4·19
K_2O	0·48	1·94	0·96	1·09	2·32	1·96	1·46	1·82	2·91	2·40
H_2O+	1·13	2·35	1·34	1·68	2·00	0·75	0·55	1·11	0·74	0·75
H_2O-	0·12	0·20	0·12	0·10	0·11	0·40	0·45	0·17	0·26	0·18
CO_2	—	tr.	0·17	—	nil	nil	nil	—	nil	nil
TiO_2	1·18	1·37	3·17	2·60	1·02	1·30	1·05	1·76	0·82	1·36
MnO	0·13	0·16	0·34	0·21	0·10	0·14	0·25	0·07	tr.	0·04
P_2O_5	0·20	0·22	0·20	0·51	0·43	0·24	0·15	0·69	0·37	0·42
	100·61	99·93	100·10	99·98	100·01	100·03	99·81	100·31	100·09	100·12*

* Includes SrO, 0·04; S, 0·34.

NORMS

	1.	A.	B.	2.	C.	D.	E.	3.	F.	4.
Qz	—	—	2·64	—	—	—	0·12	9·60	6·48	8·40
Or	2·78	11·12	5·56	6·67	13·34	11·68	8·90	10·56	17·24	13·34
Ab	14·15	9·96	28·82	28·82	23·06	29·87	27·77	25·15	34·06	35·63
An	47·82	26·41	27·80	35·31	31·14	20·29	25·02	30·30	22·52	25·85
Ne	—	—	—	—	3·12	—	—	—	—	—
C	—	—	—	—	—	—	—	3·26	—	0·82
Di	2·48	14·46	8·84	0·46	4·73	15·60	10·91	—	—	—
Hy	23·61	9·91	16·00	15·03	—	14·64	22·67	10·26	13·65	7·08
Ol	2·56	19·65	—	3·07	15·42	2·50	—	—	—	—
Il	2·28	2·74	6·08	5·02	1·98	2·43	1·98	3·34	1·52	2·58
Mt	3·25	2·78	2·09	2·55	4·18	1·39	1·16	5·10	2·55	3·25
Ap	0·34	0·34	0·47	1·34	1·01	0·34	0·34	1·68	1·01	1·01
Py	—	—	—	—	—	—	—	—	—	0·92
Cc	—	—	0·50	—	—	—	—	—	—	—

MODES

	1.	A.	B.	2.	C.
Quartz	—	—	5·87	0·9	—
Orthoclase	—	—	1·62	—	—
Plagioclase	—	34	46·04	55·3	43·7
Augite	—	5	—	—	—
Hornblende	N.D.	58	36·92	31·4	43·9
Biotite	—	—	9·67	—	10·2
Accessories	—	2	—	2·4	2·2
Chlorite	—	—	—	10·0	—

1. Basic diorite, Craig a Chrochaidh.
A. Fine-grained hornblende-bearing gabbro, E. of Lochan Beinn Damhain (Nockolds, 1941).
B. Basic rock of dioritic lens N.E. of Black Shoulder, S. of Cairnsmore summit (Deer, 1935).
2. Diorite, Allt Carn a Chlamain, quarter of a mile from junction with the Allt Feadhbhuinidh.
C. Medium appinitic diorite, E. of Head of Lochan Beinn Damhain (Nockolds, 1941).
D. Pyroxene-mica diorite, W. of Garabal Farm (Nockolds, 1941).
E. Pyroxene-mica diorite, medium diorite of Arrochar complex. Allt Coiregrogain, 1 mile south-west summit of Ben Vane (Anderson, 1935).
3. Quartz diorite, Allt na Maraig, 400 yards from junction with the Tilt.
F. Fine-grained quartz diorite, E. of Garabal Hill (Nockolds, 1941).
4. Quartz-mica diorite, 600 yards west of Conlach Mhor at head of Feith Uaine Bheag (Anal. Nos. 1–4, W. A. Deer).

(Ab_{54} $\alpha' = 1{\cdot}552$), more granular in texture, and free from included grains of amphibole. This change in the plagioclase is accompanied by the appearance of abundant apatite, a little quartz and the gradual conversion of the amphibole to a variety indistinguishable from the green amphibole of the typical diorite. During the formation of this amphibole sphene develops along the cleavages, a little epidote is formed, and the pyroxene cores disappear. These features are regarded as strong indications that the pyroxene-bearing diorites represent an early stage in the hybridization of a gabbroic rock by a more acid magma.

The analysis of this basic variety of diorite (Table 1, No. 1) is compared with the "dioritic" lens of the Cairnsmore of Carsphairn intrusion (Deer, 1935) and the fine-grained hornblende-bearing gabbro of the Garabal Hill–Glen Fyne complex (Nockolds, 1941). The Glen Tilt rock has a notably high content of alumina due to a higher proportion of plagioclase than is present in either of the other intrusions. The rock is poorer in potash but much of the potash content of the Garabal Hill gabbro is due to intense late sericitization of the plagioclase, while the Cairnsmore rock is the first of a series of hybrids characterized by a rapidly increasing percentage of potash. The basic diorite is close in composition to the medium appinitic diorite of Garabal Hill. It would be doubtless more closely matched by the pyroxene-bearing variety of the appinitic diorite which also contains a more basic plagioclase than the normal type, and is considered by Nockolds to be xenocrystal in origin.

III. Quartz-Diorites and Quartz-Mica Diorites

A complete gradation may be observed between the diorites, described in the previous paragraph, and the quartz-mica diorites. Included in the quartz diorites are those rocks in which the ratio of hornblende to biotite is greater than 3 : 1, while in the typical quartz-mica diorites hornblende is present in small amounts and biotite is the main ferromagnesian mineral.

The quartz diorites are lighter coloured than the diorites but similar, even textured, medium-grained rocks. The plagioclase occurs mainly in long tabular hypidiomorphic and idiomorphic crystals up to 1 cm. in length; the zoning, from Ab_{42} ($\alpha' = 1{\cdot}558$) to Ab_{67} ($\alpha' = 1{\cdot}544$) is frequently irregular and patchy. The amphibole, invariably smaller in grain-size than the felspar, varies in colour from γ = brown-green, α = pale yellow-green, to γ = dark green, α = light yellow, $\gamma = 1{\cdot}678$, $\alpha = 1{\cdot}660$ with $\gamma \wedge c$ varying between 16° and 20°. Occasionally the single amphibole crystals are replaced by a small aggregate of a green variety, while others are altered to irregular plates of biotite with $\gamma = \beta = 1{\cdot}630$, $\alpha = 1{\cdot}593$. The percentage of FeO

in the biotite was determined for comparison with the biotite from the intermediate hybrid. As the γ values indicated the FeO is lower in the diorite biotite, 13·64 per cent, compared with the biotite (Deer, 1938*a*) from the hybrid, 17·99 per cent. A similar increase in the percentage of FeO with increasing acidity of the parent rock has been noted previously in the biotites of the Carsphairn complex (Deer, 1938*b*). Quartz, forming up to 10 per cent of the rock, is interstitial in habit and occupies the wedge-shaped areas between the plagioclase. Large numbers of small apatite crystals occur enclosed within the plagioclase and biotite; sphene is also present, usually in association with the hornblende.

Two representative examples of this series have been analysed (Table 1, Nos. 3 and 4), and they show the same characteristically high alumina content which is such a constant feature of the dioritic rocks of the complex. Thus compared with the fine-grained quartz diorite of Garabal Hill, the only significant difference is the relatively high alumina and low silica content.

IV. Appinites and Related Types

Appinites were defined in the Ben Nevis and Glen Coe Memoir (Bailey, 1916) as the plutonic equivalents of the hornblende vogesites and spessartites, although no chemical data was presented to show their affinities with these hypabyssal rocks. Subsequently the term appinite has been applied to a variety of Scottish hornblendic rocks.

The original appinites are described as medium to coarse textured rocks consisting predominantly of green or brown idiomorphic hornblendes in a groundmass containing variable proportions of plagioclase, orthoclase, and quartz. Olivine (pseudomorphs), augite, and biotite are described as sometimes being present, and apatite appears as a conspicuous accessory. Although these rocks occur in very small masses nevertheless they show a wide range of mineralogical composition, and Bailey regarded such transitional types as linking the appinites with the mica diorites and monzonites. A number of thin sections of the appinitic rocks of the Glencoe and Loch Shiel area have been examined, and except for the characteristic abundant amphibole, a great variability in mineralogical composition occurs. In some specimens two generations of hornblende are present but in many there is little or no tendency for the development of phenocrysts. In these rocks in which two hornblende generations are present a diopsidic augite usually occurs in association with the smaller green hornblendes and biotite is characteristically absent. In those varieties showing no development of hornblende phenocrysts biotite is usually present in fair quantity and in certain cases becomes the most conspicuous ferromagnesian component. The felspathic constituents show

a wide variation, in some rocks acid plagioclase occurring to the exclusion of potash felspar, while in others orthoclase and quartz, sometimes in graphic intergrowth are predominant non-ferromagnesian minerals. Apatite, sphene, epidote, and calcite are commonly relatively abundant accessories.

TABLE 2.—APPINITES

	1.	2.	3.	A.	B.	C.
SiO_2	50·41	54·56	57·80	44·65	40·26	48·68
Al_2O_3	12·42	13·00	8·76	12·40	15·74	17·66
Fe_2O_3	2·54	1·11	3·27	5·47	3·44	2·17
FeO	7·12	5·08	5·41	9·03	7·95	6·72
MgO	10·22	9·19	9·80	11·80	12·09	7·78
CaO	11·76	10·81	8·05	9·85	12·03	9·32
Na_2O	2·12	2·73	3·02	1·90	2·25	2·22
K_2O	1·11	1·85	2·01	0·89	1·36	1·90
H_2O+	0·51	0·41	0·63	1·50	0·48	1·74
H_2O-	0·28	0·13	0·13	0·20	1·75	0·22
TiO_2	1·35	0·96	0·83	1·90	2·42	1·34
MnO	0·05	0·20	0·11	0·03	0·03	0·13
P_2O_5	0·28	0·29	0·14	0·25	0·04	0·03
CO_2	—	—	—	Nil	0·03	Nil
	100·17	100·32	99·96	99·87	99·87	99·91

NORMS

	1.	2.	3.	A.	B.	C.
Qz	—	—	6·06	—	—	—
Or	6·67	11·12	11·68	5·56	—	11·12
Le	—	—	—	—	6·54	—
Ab	17·82	23·06	25·15	16·24	—	18·34
Ne	—	—	—	—	10·22	—
An	21·13	17·51	4·73	22·52	28·63	33·08
Di	29·34	27·58	27·39	21·15	21·22	9·85
Hy	11·34	15·10	17·43	2·33	—	10·57
Ol	6·38	1·26	—	18·90	22·81	8·88
Il	2·58	1·98	1·52	3·65	4·56	2·58
Mt	3·71	1·62	4·87	7·89	4·87	3·25
Ap	0·67	0·67	0·34	—	—	0·34

MODES

	1.	2.	3.	C.
Quartz	6·6	2·8	18·5	3·3
Orthoclase	2·6	9·8	14·6	—
Plagioclase	26·2	29·0	7·5	31·3
Hornblende	61·6	45·6	59·4	50·1
Pyroxene	—	9·8	—	1·9
Biotite	—	—	—	11·4
Accessories	3·0	3·0	—	2·0

1. Appinite, 1,500 feet about the Tilt in the Allt Clachaig.
2. Pyroxene-bearing appinite, head of Allt na Stabnilt.
3. Quartz-orthoclase appinite, 700 yards north-east of the head of the Allt a'Chama Choire (Anal. Nos. 1–3, W. A. Deer).

A. Appinite, quarter of a mile south-south-east A' Chrois, Argyll (Anderson, 1935).

B. Appinite, south-east summit, Ardsheal Hill (Walker, 1927).

C. Coarse appinitic diorite, south of Garabal Hill (Nockolds, 1941).

In the description of the Strontian granite (MacGregor and Kennedy, 1932), reference is made to ultrabasic, basic, and acid rocks of the appinite suite. Here they occur as xenolithic masses within the tonalite, granodiorite, and biotite granite of the complex.

As far as the writer is aware the first rock described as an appinite to be analysed (Table 2, No. B) is from Ardsheal Hill (Walker, 1927). Here the appinite is mapped as two isolated outcrops some fifty yards across, yet in spite of the small size, great variation in mineralogical composition occurs from felsic types containing 20 per cent mafic constituents to hornblendites comparable with those of Colonsay. As described by Walker the typical appinite contains between 60 and 70 per cent of a greenish-brown amphibole, often enclosing well defined cores of colourless pyroxene, the plagioclase is an andesine-labradorite and a little orthoclase and quartz is present. The appinite is intimately associated with the kentallenite of the intrusion, the two rocks forming adjacent schlieren, a feature which is repeated in the close association of the various textural and mineralogical varieties of the appinite itself. The analysed rock contains 80 per cent mafic constituents, mainly hornblende, and is poorer in silica and richer in alumina and magnesia than any of the Glen Tilt appinites.

Appinites are described from the Arrochar complex (Anderson, 1935*b*), occurring as very small masses enclosed within the diorites of the complex. Considerable variation occurs in the amount of hornblende present and in at least one locality, Creag Tharsuian, the appinite is developed marginally around pyroxenite. Appinitic rocks are associated marginally with the smaller diorite intrusion to the east of Loch Lomond (Anderson, 1937). The analysed Arrochar appinite (Table 2, No. A) consists essentially of brown hornblende containing a few cores of pyroxene together with plagioclase, orthoclase, and quartz. Two hornblende generations are not recorded for this rock, and the brown hornblende is considered to be a primary constituent and not secondary after pyroxene as is the davainities. Anderson has also described appinitic rocks from the Glen Falloch area (Anderson, 1937) which are stated to be identical with those of the Arrochar complex and in both areas they are considered to be special facies of the diorites. Small areas of appinite occur within and associated with the Ben Nevis intrusion (Anderson, 1935*a*). They are described as small irregular bosses or veins within the surrounding schist. In spite of their small size Anderson recorded a wide variation in mineralogical composition; although a considerable range in the optical properties of the hornblende was noted, the presence of two hornblende generations is not recorded. The plagioclase of these rocks is an oligoclase, and quartz and potash felspar are present in the more leucocratic variations.

Appinite has been recorded associated with the granodiorite, diorite, and hypersthene-quartz-diorite of the Abercorn region, Northern Rhodesia (Deans, 1938). This rock shows the development of two generations of hornblende and consists approximately of 50 per cent phenocrystal hornblende in a matrix of andesine-oligoclase with microcline and quartz occurring in poikilitic plates enclosing the second smaller amphibole generation. The rock differs from the typical Glen Tilt appinite in the apparently closer identity of the two hornblende generations, but although this is a feature of the orthoclase bearing appinites of Glen Tilt, without further optical data it is not possible to make any close comparison with the Scottish appinites.

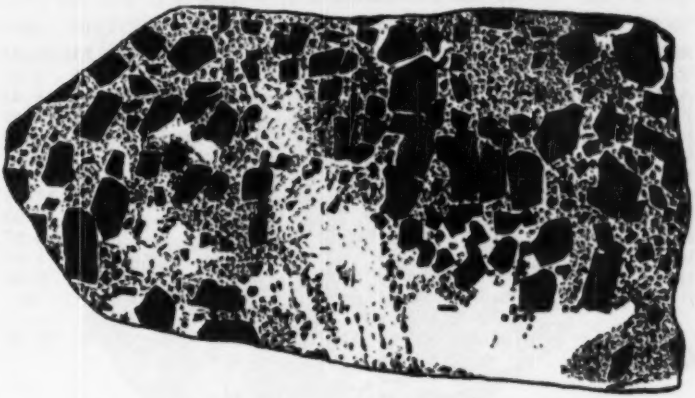
More recently appinite (" hornblendite ") and coarse and medium appinitic diorites have been described from the Garabal Hill–Glen Fyne igneous complex (Nockolds, 1941). Both the coarse and medium appinitic diorites are markedly undersaturated and the rocks are closer in chemical composition to the Glen Tilt diorites. Richer in plagioclase and carrying an appreciable amount of biotite they have a higher alumina content than the typical Glen Tilt appinites. Although the brown hornblende is much altered to a later green variety two distinct generations of hornblende are not developed. It has been suggested that the Garabal Hill appinitic diorites are accumulative rocks developed during the later stages in the crystallization differentiation of pyroxene-mica-diorite magma and are thus the youngest member of the accumulative series periodotite, gabbro, appinite.

In this paper the Glen Tilt rocks in which amphibole, largely as phenocrysts, exceeds 45 per cent are included in the term appinite. Although up to 10 per cent monoclinic pyroxene may be present in some varieties (Table 2, No. 2) the Glen Tilt appinites are essentially hornblende plagioclase rocks with varying proportions of orthoclase and quartz.

In the typical Glen Tilt appinite two generations of hornblende are present (Deer, 1938*c*). This feature, and the development of hornblende phenocrysts, is a distinctive characteristic which, apart from the high percentage of hornblende, serves to distinguish these rocks from the diorites of the complex. Plagioclase rarely exceeds 30 per cent and is normally an acid oligoclase although in some varieties the plagioclase is even richer in the albite molecule. In some of the Glen Tilt rocks of appinitic type orthoclase is the dominant felspar and this variety may form a link with the Ach'uaine hybrids (Read, 1928), which have been compared by some writers with the appinites, although the latter differ from the Ach'uaine hybrids in the absence of biotite.

The typical Glen Tilt appinite (Table 2, No. 1) is a coarse rock with very conspicuous hornblendes up to three-quarters of an inch in length. These rocks frequently show heterogeneity, consisting of finer and

coarser-grained areas (Text-fig. 1), and are similar to the description of the hornblende-felspar rock from Allt Coire na Fearna (Read, 1931), which is considered to be " formed by the invasion of a basic hornblendic rock by oligoclase-rich magma of a trondhjemitic facies ". The same author also suggested that the Allt Coire na Fearna rock is identical with the appinites of the south-west Highlands. A similar



TEXT-FIG. 1.—Typical Glen Tilt appinite. Large crystals are of brown hornblende, finer grain areas consist of second generation green hornblende and plagioclase. The more felspathic areas are light coloured. Scale : 2/3 natural size.

rock is described from the Glen Doll complex (Barrow and Craig, 1912), and the authors of the memoir state that it closely resembles the Glen Tilt diorite (i.e. the appinite).

The heterogeneity of the appinites is due to the grouping of the majority of the hornblende phenocrysts, separated only by a thin margin of interstitial felspar, contrasting with more felspathic areas rich in plagioclase enclosing many small idiomorphic hornblendes. In thin section the large hornblendes are brown in colour and rimmed with a narrow zone of a green variety. The composition of this hornblende (Table 3, No. 2) is close to that from the diorite but shows higher silica and alumina, lower total iron and higher Fe_2O_3/FeO and Na_2O/K_2O ratios. It has a similar composition to the brown hornblende from the medium appinite of Garabal Hill, the latter being considered (Nockolds, 1941) to be a mineral of early crystallization. Both are rich in Al_2O_3 and TiO_2 and the only significant difference is the higher Fe/Mg ratio of the Garabal Hill mineral. The brown hornblende is strongly pleochroic with $\gamma \wedge c = 15°$, $\gamma = 1{\cdot}672$,

2V = 70°, while the green hornblende of the rim is only moderately pleochroic with $\gamma \wedge c = 19°$. Although the conversion of the brown hornblende to the green variety usually occurs marginally the change has also been observed to take place in irregular patches. In both cases, however, the actual transition from the brown to the green variety is sharp and accompanied by an increase in the extinction angle.

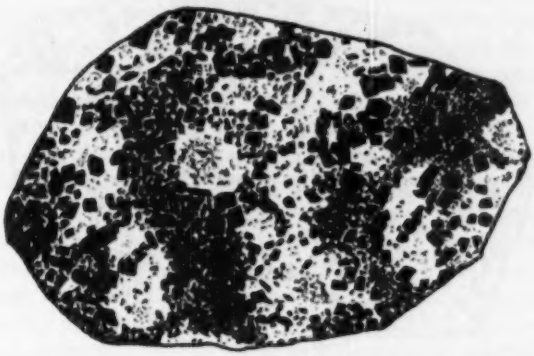
TABLE 3.—HORNBLENDE ANALYSES

	1.	2.	3.	4.	5.	6.	7.
SiO_2	42·11	43·01	41·61	48·92	43·65	45·50	48·32
TiO_2	2·76	2·87	2·57	1·21	1·2.	1·73	1·43
Al_2O_3	10·05	12·01	12·16	5·88	8·01	9·66	6·43
Fe_2O_3	2·82	3·35	4·04	6·50	4·86	6·06	5·45
FeO	15·14	9·07	12·05	7·79	10·87	6·90	7·90
MnO	0·24	0·19	tr	0·17	0·56	0·18	0·13
MgO	11·48	14·00	11·44	14·32	13·96	14·61	14·82
CaO	11·34	11·79	11·63	11·37	12·16	11·24	11·99
Na_2O	1·01	1·08	1·85	1·20	—	1·20	0·99
K_2O	1·43	1·01	0·58	0·71	—	0·92	0·67
H_2O+	2·02	1·40	2·33	1·37	—	1·73	1·61
H_2O-	0·06	0·06	0·21	0·18	—	0·19	0·06
F	---	0·84	—	0·27	—	tr.	tr.
	100·46	100·68	100·47	99·89	95·33	99·92	99·80
Less O for F		0·36		·11			
		100·32		99·78			
γ	1·680	1·672	1·683	1·664	1·663	1·669	1·671
2V	66°	70°	78°	78°	72°	77°	76°
$\gamma \wedge c$	15°	15°	23°	19°	21°	18°	20°
Total Fe as FeO : MgO	1·45	0·86	1·37	0·95	1·05	0·84	0·76

1. Green hornblende, diorite.
2. Brown phenocrystal hornblende, appinite.
3. Green-brown hornblende, medium appinitic diorite (Nockolds, 1941).
4. Small green hornblende, appinite.
5. Green hornblende, medium granodiorite (Nockolds, 1941).
6. Brown hornblende, pyroxene-bearing appinite.
7. Greenish-brown hornblende, quartz-orthoclase appinite.

The smaller hornblendes of the more felspathic areas are green in colour and appear to be identical with the green hornblende margins of the brown variety. They form idiomorphic crystals with 2V = 78°, $\gamma \wedge c = 19°$, $\gamma = 1·664$. The composition of the small green hornblendes (Table 3, No. 4) is strongly contrasted with the large brown phenocrysts, the low silica and low alumina, and the Fe_2O_3/FeO ratio shows a marked increase while titania is considerably lower. The second generation hornblende may be compared with the hornblende from the porphyritic granodiorite of Garabal Hill. Compared

with the phenocrystal hornblende and the brown hornblende of the medium appinitic diorite there is a greater contrast in the composition of these two minerals, nevertheless they both vary in the same direction, namely higher silica and lower alumina and titania. The Fe/Mg ratios of the hornblendes from the two intrusions are not very different but, in the case of the Glen Tilt minerals the ratio in the early and late hornblende is not significantly different. At Garabal Hill the mineral from the later and more acid rock shows a decrease in the Fe/Mg ratio. Nockolds considers that this decrease is due to the presence of abundant biotite in the porphyritic granodiorite and has ascribed the

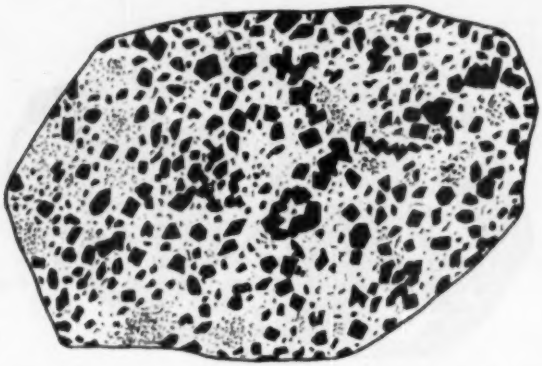


TEXT-FIG. 2.—Appinite showing more heterogeneity. The light coloured areas consist of large plates of plagioclase enclosing small green, second generation hornblendes. Scale : 2/3 natural size.

low alumina content of the mineral to the same cause. The plagioclase of the appinite is an oligoclase-andesine Ab_{68} ($\alpha' = 1{\cdot}543$) with well developed albite and pericline twinning. Some of the plagioclase crystals show slight flexuring of the twin lamellae and a number of the hornblende stepped fractures. It is unlikely that these features are due to post-consolidation movements as they are not present in the surrounding diorites and it is considered that they were developed during the formation of the appinite. A small amount of potash felspar is present together with conspicuous and irregular pools of quartz.

Many of the appinites show a more marked heterogeneity than those described above. These rocks are distinctly patchy in appearance and consist partly of large idiomorphic hornblendes in a light-coloured matrix of felspar and quartz and partly of small hornblendes enclosed in large plates of plagioclase (Text-fig. 2). Although in thin section some crystals show small cores of the brown variety, most of the hornblendes are seen to be green in colour. Conversion of the brown

hornblende to biotite has also been observed where the amphibole is in contact with potash felspar. This instability of brown hornblende in the presence of potash felspar was noted as a characteristic feature in the development of the hornblende-hybrids of the Carsphairn complex (Deer, 1935). The plagioclase forms large plates enclosing small grains of hornblende and pyroxene, the latter largely converted to green hornblende, and many very small apatite needles. Corrosion of the plagioclase by potash felspar, mainly by penetration along the twin planes, may sometimes occur where the two felspars are adjacent.



TEXT-FIG. 3.—Pyroxene-bearing appinite. Large idiomorphic crystals are brown hornblende. Lighter coloured areas consist of larger plagioclase plates with small crystals of second generation green hornblende and diopsidic pyroxene. Scale : 2/3 natural size.

The pyroxene-bearing appinites (Table 2, No. 2) are medium to coarse-grained rocks with conspicuous phenocrysts of hornblende (Text-fig. 3) forming squat crystals, with well developed $(0\bar{1}1)$, (011), $(0\bar{1}0)$, (110), and (010) faces, enclosed by plagioclase and containing smaller grains of hornblende and pyroxenes. In thin section the hornblende phenocrysts, $\gamma = 1{\cdot}669$, $2V = 77°$ and $\gamma \wedge c = 18°$ are pleochroic in browns and usually rimmed by a narrow zone of green hornblende with $\gamma \wedge c = 19°$: less frequently a more patchy replacement of the brown hornblende by the green variety is developed. No alteration of hornblende to biotite occurs, but chlorite accompanied by the separation of sphene, is not infrequently produced from the alteration of the amphibole. This amphibole has been analysed, and compared with the brown hornblende phenocrysts of the typical appinites there is less replacement of silica by alumina, but apart from this feature, and a higher Fe_2O_3/FeO ratio the composition of the two varieties shows little contrast. The diopsidic pyroxene occurs mainly in clusters

but may also develop round the small grains of the green hornblende. The plagioclase Ab_{75} ($\alpha' = 1{\cdot}541$), in common with the felspars in the intermediate types of Ach'uaine hybrids (Read, 1928), encloses many small green hornblendes and pyroxenes. A little interstitial quartz is present and apatite is a constant but not abundant accessory.

V. Quartz-Orthoclase Appinites

This variety of appinite occurs only on the badly exposed ground of the Aonach na Moire close to the margins of the main granite intrusion, and has not been found in contact with other rocks of the complex. It consists essentially of hornblende, orthoclase, and quartz with some plagioclase (Table 2, No. 3). The hornblende forms subhedral grains showing no phenocrystal development, and the rock is uniformly medium-grained. Many of the hornblendes are zoned from brown to green with the core γ = brown, β = light brown, α = yellow-green, the periphery γ = green, β = light green, α = light yellow-green, and $\gamma \wedge c$ varies from 20° to 23°. It was not possible to separate the brown from the green variety, nevertheless the composite analysis shows a very close comparison with the small green hornblende of the typical appinite having the same high silica and low alumina, and similar Fe_2O_3/FeO ratio. The orthoclase ($\gamma' = 1{\cdot}527$) and quartz form large irregular grains, the former poikilitically enclosing the hornblendes, and adjacent to the plagioclase Ab_{66} ($\alpha' = 1{\cdot}538$) develops a myrmekitic border. The rock contains no biotite and the accessories, sphene, apatite, and ore are not abundant. Although the mineral assemblage and chemical composition of this rock differ from the other analysed appinites transitional varieties occur within the diorites. These are rocks rich in hornblende in which the amphibole occurs both as medium size phenocrysts and as small grains, with plagioclase and orthoclase in approximately equal amounts, and as much as 15 per cent quartz. The larger hornblendes of these rocks are mainly light brown in colour with a deep brown core, although in some cases the core of deep brown hornblende is rimmed by a green variety. The smaller green hornblendes, with γ = deep green, α = pale yellow-green, rarely show inclusions of sphene. The plagioclase poikilitically encloses the smaller hornblendes and shows marginal corrosion in contact with orthoclase. The latter forms large irregular plates enclosing corroded laths of plagioclase and myrmekitic intergrowths sometimes develop at the junction of the two felspars. Quartz, although interstitial, is an important constituent occupying wedge-shaped areas between the other minerals. Apatite and sphene are common accessories. The lack of stability of the large brown hornblendes observed in the typical appinites and demonstrated by the partial or complete conversion of the brown to a green hornblende, is again illustrated

by these transitional rocks, the green hornblende of which has almost identical optical properties as those, both of the quartz-orthoclase appinite and the small green hornblendes of the typical appinites.

The characteristic feature of the complex is the absence of sharp contacts, each rock type passes by a more or less gradual transition from one variety to another. From examination of thin sections the following facts based on the relationships between the plagioclase and amphibole in the diorites and appinites are significant. In the typical diorites the crystallization of the plagioclase began before the hornblende which is monovarietal. The felspar also occurs in great preponderance and the hornblende rarely exceeds 35 per cent of the rock. In contrast the appinites show a much greater percentage of amphibole, and the phenocrystal hornblende is of earlier formation than the felspar. The development of a second variety of hornblende highly contrasted in composition with the phenocrystal is a distinctive feature of the appinites which is completely absent in the typical diorites. A further point of interest is the acid composition of the plagioclase in the appinites. These facts make it difficult to regard the appinites as a product of the hybridization of an earlier, more basic rock of the complex by the diorite. Moreover it is believed that such rocks have been recognized in the complex, and are represented by the basic diorites. It is equally difficult to reconcile the association of early and late formed hornblendes, of which the latter only is equilibrium with the acid plagioclase of the appinite, with an accumulative mode of origin such as Nockolds has ascribed to the appinitic diorites of Garabal Hill. The textural characteristic of many of the Glen Tilt appinites is their heterogeneity, a feature suggestive of a hybrid origin. The hybridization of hornblende-schist both as xenoliths and contact rocks will be described in a later paper when the possible formation of the Glen Tilt appinites from these rocks will be examined.

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The Devolatilization Equation for South Wales Coals

By F. M. Trotter

Summary

Recent published work on the origin of the South Wales coals has shown that the " original deposition theory " is invalid ; the pronounced devolatilization of the coals is due to a cause which operated after the formation of all of the seams and the rate of change of the volatiles is governed by a function which can be expressed as an empirical equation. Nevertheless minor variations in coal seam volatiles arising from differences in original composition of vegetation are recognized, and of several examples one is given from the Northumbrian geo-syncline where the highest volatiles are in the lowest Carboniferous Limestone coals and where the extreme variation throughout a sequence of 7,000 feet of coal-bearing strata is 11%. The minor variations lessen progressively if the coal seams become devolatilized. As illustrated by examples from American and European fields, a most important factor in coal seam devolatilization is orogenic pressure with incidental frictional heat.

The present basis of comparison of essential coal-substances (fixed carbon and volatiles) is shown to be empirical ; a mathematical comparison should be based on the original composition of the coal (not peat) substance. It is shown that 50% fixed carbon and 50% volatiles (d.a.f.) constitute good average figures for the original composition of the coal substance of Carboniferous coals. Loss of weight in devolatilized coals is suffered only by the volatiles so that the best basis of mathematical comparison is the 50% fixed carbon (d.a.f.). The volatile percentages of the South Wales seams when calculated on this basis all show a pronounced drop in values, and on the 50% fixed carbon basis it is necessary to find a new controlling function for the rate of change of volatiles in coal seams lying in vertical sequence. It is found that this is best expressed by the following exponential equation :

$$v_2 = v_1 e^{-2 \cdot 8.10^{-4} y \cos \theta}$$

where v_2 and v_1 represent the volatiles of the lower and upper seams respectively, y is the vertical distance in feet of v_2 below v_1, and θ is the angle of dip of the zero plane previously determined in South Wales as 5°.

NORMALLY a proximate analysis of a coal gives percentages of volatiles, fixed carbon, water, and ash. Volatiles and fixed carbon, however, are regarded as constituting the essential coal substance and for purposes of comparison between coal-samples the coal substance is expressed on a dry ash free (d.a.f.) basis. The theoretical basis of comparison is 100 grams of dry ash-free coal, and a coal, for example, of 15% volatiles and 85% fixed carbon is regarded as being directly comparable with a coal of 30% volatiles and 70% fixed carbon. This type of comparison is the accepted current usage and it should be made plain at the outset that this basis of comparison is and remains valid for commercial purposes. The present basis of comparison could be also the theoretical basis of comparison if the coal substance has retained an unaltered composition since it became coal. If, however, the coal substance has been subjected to influences that

have caused subsequent changes, as for example a loss of volatiles, then the present accepted basis of comparison is statistical or empirical only, and calculations are necessary before the mathematically correct comparison can be made between coals of different volatile matter content. To illustrate with an example of obvious loss of volatiles driven off by heat during the intrusion of an igneous dyke into a coal seam, the analysis of the unaffected coal (d.a.f.) being: volatiles 43%, fixed carbon 57% ; and of the cinder coal : volatiles 5%, fixed carbon 95%. Now in 100 grams of unaltered coal substance there are 43 grams of volatiles and 57 grams of fixed carbon and in 100 grams of cinder coal there are 5 grams of volatiles and 95 grams of fixed carbon. A mathematical comparison can be made on the basis of the same quantity of fixed carbon and as only volatiles are driven off the appropriate basis is the 57 grams of fixed carbon of the unaltered coal. On this basis the amount of volatiles in the cinder coal is :

$\frac{5}{95} \times \frac{57}{1} = 3$ grams. Thus the mathematical comparison is between the 43% volatiles in the unaffected coal and 3% volatiles in the cinder coal whereas the statistical or empirical comparison is between 43% volatiles and 5% volatiles.

The first question then to be decided before attempting to make a mathematical comparison between coal substances is whether they, the coal substances, have remained unaltered, or whether they have been subjected to influences since their formation as coal (coalification) which have caused loss of volatiles.

Strahan and Pollard (1908) considered that the great range in the volatile matter of the South Wales coals was due to original differences in the composition of the coal substance. Among authors holding a similar view may be cited Mackensie Taylor (1926–8) and Fuchs (1946). On this view on deposition anthracite was formed as anthracite, carbonaceous coal as carbonaceous coal, and so on with decreasing rank of coals. If this view be correct then the present accepted basis of comparison is both empirically, statistically, and mathematically correct. Established practice could not be altered until the " original deposition theory " had been proved wrong beyond reasonable doubt. Thus, of necessity the universally accepted basis of comparison was used by the writer (Trotter, 1949) in a paper to the Geological Society wherein it was shown that the volatile matter of South Wales coal seams varied with the square of the distance of the seam from a particularized plane (the zero plane) which was inferred to be the plane of the Main Thrust. From the proposition the following equation was derived : $V_2 = \left(\frac{1450\sqrt{V_1} - y \cos \theta}{1450}\right)^2$ or

$v_2 = \left(\frac{2050{\cdot}6\sqrt{v_1} - y \cos \theta}{2050{\cdot}6}\right)^2$ where V_1 and V_2 respectively represent twice the volatile content and v_1 and v_2 the volatile content of an upper and a lower seam in vertical sequence, y the vertical distance measured in feet between the seams and θ the angle of inclination of the thrust plane.

In obtaining the equation the analytical results of true coals only were available. Other types of coal are very rare in South Wales but if we had the data it is possible that a similar equation might be devised for Boghead coals (torbanites, cannels, etc.). For the present we exclude these coals from our considerations.

With the discovery of a function which governs the rate of change of the volatiles in the South Wales coal seams it necessarily follows that the change itself is due to a cause which is subsequent to the formation of the coal substance. Although several contributors to the discussion of the writer's Geological Society paper advanced other causes to account for the function which controls the rate of change of the volatiles, there was general agreement that the cause itself was a subsequent one. Again in a recent article on the subject the subsequent nature of the cause is accepted by Mr. John Roberts (1949), and it may be now taken as established that differences in the original composition of coal are not the primary cause of the pronounced variation in the volatile content of the coal seams of South Wales. It follows that, at least in coalfields exhibiting pronounced variation in the volatile matter of coals, the present basis of comparison between coal substances must be regarded as empirical or statistical. Before attempting to find a truer basis of comparison, however, it is pertinent to recall that there are original differences in the composition of present-day peats; and in the past similar differences in the composition of peats have given rise to differences in composition of the coal substances which after coalification are represented by durain, fusain, vitrain, and clarain in true coals. These differences are real and later in this note (p. 204) an example is given from the fat bituminous coals of the Northumbrian geo-syncline. It is only necessary here to mention that these differences are not too great and that they become less pronounced as the coal substance becomes progressively devolatilized by a subsequent cause. In other words the coal-type band which embraces these differences of original composition narrows progressively with rising rank of coal, so that in South Wales where fat high-volatile non-caking bituminous seams and coals of lower rank are absent and where very high rank coals are in force it does not vitally impair the results obtained by using the devolatilization equation.

The So-called "Law" of Hilt

Before proceeding to a truer basis of comparison of coal seam volatiles it is advisable to clarify the confusion caused by Professor O. T. Jones' (1949) revival of Hilt's so-called "law" and his conception of a Hilt's "rate" of decrease of volatiles in coal seams with depth. The facts are that the volatile content matter of coal seams can show either a local or regional decrease towards igneous intrusions or towards those regions where the maximum orogenic pressure has been exerted. Where the pressure has been intense and has generated frictional heat a marked devolatilization of the coal seams has taken place and normally the direction of maximum devolatilization, whether local or regional, can be resolved into two components—horizontal and vertical. In coalfields which have not been subjected to intense orogenic pressure no marked devolatilization of the coal seams is to be found. The relatively small differences in volatile matter of the seams displayed in such fields follows no particular rule; they arise from differences in composition of the original vegetation, now reflected after coalification, in the varying amounts of fusain, durain, vitrain, and clarain found, not infrequently as bands, within the coals of these coalfields. A recent example from Lancashire may be cited where the volatiles of different sections of one seam, analysed by the Coal Survey (N.C.B.), Chester, differed by as much as 6·8%.

A relationship between regions of tectonic disturbance and anthracitization was first pointed out in this country by Mr. J. Roberts (1922). Recently (1950) he has listed areas where intense tectonic disturbance have resulted in the formation of anthracites. They include the Pennsylvanian anthracites, first described in this connection by White (1913), the Rocky Mountain anthracites in Canada, the anthracites and per-anthracites of the Alps, the anthracites of the Donetz basin and, of course, the South Wales anthracites. To these examples of Roberts may be cited the coalfields within the well-known Armorican arc of compression (sometimes referred to as the Armorican front) which extends from Europe across Southern England to at least as far as Pembrokeshire, in Wales. It includes the Ruhr coalfield, Germany, the fields of Charleroi, Leige, etc., in Belgium, the Pas de Calais coalfield, in France, the Kent field, and farther west the Gloucester–Somerset field, including in this area the carbonaceous culm of Devon, in England, the Monmouth–Glamorgan–Carmarthenshire field, and the detached Pembrokeshire field, in South Wales.

Characteristic features shown to varying degree in these fields are folding and/or overthrusting. Devolatilization of the coal seams of these fields within the Armorican arc is pronounced; indeed, in several of them the metamorphism has produced anthracites or

semi-anthracites. As a non-British example we may instance the Pas de Calais coalfield, where within one Group, the Group de Bruay, and bounded on the north-east and south-west by the Faille de Sains and the Faille de Ruit respectively, the volatiles range from 45% to 9%.

In most of the coalfields within the Armorican arc it is possible to resolve the direction of devolatilization into a horizontal and a vertical component, and naturally in several cases it is found that the devolatilization of the seams decreases with depth. This has been observed in the Pas de Calais, in Kent, and in the main South Wales coalfields. But progressive metamorphism of a coal seam with depth in areas that have been affected by intense pressure must not be taken as an invariable rule, although, as is natural, it frequently occurs. Roberts (1950) has recently quoted the case of a seam of lignite at an elevation of 2,500 feet in Eastern Alberta which when traced to the Rocky Mountains loses volatiles to such an extent that it is an anthracite at an altitude of 4,500 feet. Nearer home we have the case of the pronounced devolatilization of the Little Limestone Coal on the Alston Block. This coal seam yields 38% to 40% volatiles within the Northumbrian geo-syncline. The coal loses its volatiles as the compressional zone of the Alston Block is approached and near Haltwhistle, at approximately Ordnance Datum, the volatiles are 33%. At an altitude of 1,000 feet A.O.D., near Slaggyford, some 7 miles to the south-south-west in a direction towards the area subjected to the most intense pressure, viz. the major thrust masses along the western side of the Alston Block, near Cross Fell, described by Professor Shotton, the volatiles of this seam are reduced to 14%.

Turning to the coalfields which have not been subjected to strong compressional influences it is found that the volatiles of the coal seams show no significant decrease with depth. *Any variation in the volatile content matter of the coal seams of these fields is due essentially to differences in composition of the original vegetation now coalified into vitrain, etc.* Numerous examples could be given, but to emphasize the invalidity of the so-called " law " of Hilt that the volatile matter of coal seams decreases with depth as emphatically re-stated by Professor O. T. Jones, examples are given of sequences which show Hilt's so-called " law " in reverse, i.e. to sequences showing an increase of volatiles with depth. We need not concern ourselves with speculations on former thicknesses of cover (now removed by denudation) however thick these may have been in the past. The examples are selected to show very substantial thicknesses of *existing* stratal cover above the seams so as to give the reader an opportunity of factually evaluating the effect of the earth's geothermal gradient. Thus, in these examples are included the deepest boring (Notown Bore) for coal in the world; and also the deepest boring (Spital) in this country to prove coal

TABLE I.—DEEP BORINGS SHOWING AN INCREASE OF COAL SEAM VOLATILES WITH DEPTH

Locality	Depth of coal from surface in feet	Volatiles d.a.f.	Moisture	Reference
Notown, New Zealand.	3,000	43·8	23·0	H. W. Wellman, New Zealand Geol. Surv.
	6,893	50·4	4·1	
		51·4	4·5	
		51·6	3·2	
Spital Bore, Lincolnshire.	4,207	37·5	4·7	A. Dawe and G. Coles in *Journ. of Inst. of Fuel*, Oct., 1948.
	4,978	42·1	2·8	
	4,993	40·0	2·8	
Dunston, Lincolnshire.	3,834	41·6	4·5	Ditto
	4,132	44·5	3·8	
Tanhouse, Lancashire.	3,089	37·1	2·3	Coal Survey Lab., Chester.
	3,403	38·0	2·1	
Earlestown, Lancashire.	1,898	38·9	4·9	Ditto
	2,253	39·5	4·2	
Cronton, Lancashire.	1,811	34·3[1]	3·9	Ditto
	2,887	38·2	2·5	

seams. For convenience of comparison all the volatiles are calculated to a dry ash-free basis.

The vertical distance between the uppermost and lowest seam of each vertical sequence varies between a minimum of 300 feet and a maximum of 3,893 feet ; the minimum depth from the surface is 1,811 feet ; the maximum depth is 6,893 feet. It is seen that the only possible effect attributable to the geothermal gradients is the *decrease in moisture* content of the coals in each case. Volatiles, by contrast, *increase* with depth in each of the listed sequences. These results should finally dispose of the tradition revived by Jones that there is a universal decrease in coal seam volatiles with depth due to geothermal gradients or, indeed, to any other cause. Hilt's so-called " law ", so far as it relates to volatiles of coal seams, is invalid. On the other hand, as indicated by the above table and supported by numerous other examples, there is, in general, a decrease in the inherent moisture content of coal seams with depth *in the seams of those coalfields which lie outside the strong compressional zones*. This loss of moisture has two notable effects on the character of the coals of such fields : (1) Since less heat is used during combustion in removing the moisture, the coals of lower moisture content (i.e. those lying at greater depth in any one vertical sequence of such fields) have

[1] A second analysis restricted to floats at 1·6 specific gravity gave a figure of 37·1%.

a higher calorific value, and (2) in bituminous coals of the same volatile content it is found that the lower the moisture content the higher the caking properties of the coal. Thus, it is a fair generality to say of the fields outside the strong compression zones that the *rank* of the coals increases with depth. This is due essentially to the expulsion of moisture, not volatiles ; but Professor Jones was dealing with volatiles in his recent article on the universal application of the so-called " law " of Hilt. His superstructures raised on the " law " collapse with the law itself. His isobaths based on an erroneous interpretation of the Notown boring, inexplicably assumed to show a decrease of volatiles with depth, and his isobath-inflated geo-synclines over South Wales and Kent disappear ; and Hilt's so-called " rate " also disappears with the so-called " law ".

The nine different rates of decrease in the volatiles of coal seams noted by Hicks (1946) in nine different and widely separated sequences in South Wales raised the following problem : was there one function which controlled the varying rates of decrease throughout the South Wales field ? The writer offered a solution to this problem in the form of the empirical equation given above. This solution also accounted for the varying isovol values and also their spacing and their varying trends as depicted by the Coal Survey on their map of the South Wales coalfield—features which had hitherto puzzled fuel technologists. The isovols of this map are based on modern analyses ; compared with this standard work any other isovol map, such as that of Professor Jones, has little or no value. Finally, it was in accord with the structural evidence.

The repetition by Professor O. T. Jones of the nine different rates of decrease of volatiles first noted by Hicks, adds nothing to our knowledge. It is obvious that each different rate can be expressed by a separate simple equation. To do so is merely to state the problem in a slightly different form. Yet this is precisely what Professor O. T. Jones did when he published the simple equations $V_1 = V_0 - hy$, with his nine different tabulated values for his " constant " h (the volatiles of the top seam and a lower seam are V_0 and V_1 respectively, and y the distance between the seams). Actually there are eleven, not nine, available sequences, each with a different rate of decrease of volatiles and, of course, the problem can be stated by eleven simple equations having eleven different values for the " constant " h. When coal seam analyses are available for each additional vertical sequence that may be proved by sinkings yet another equation containing another value for the " constant " h would be required if the problem were to be fully stated in terms of simple equations. Furthermore these remarks apply whatever power y is raised to if in each equation the appropriate cancelling adjustment is made for the value of the " constant ".

These numerous equations merely state the problem. Its solution lies in the discovery of one equation with one " constant " which satisfies all available vertical sequences.

Whether my one empirical equation satisfies the eleven vertical sequences must be left to the judgment of the reader. Here are the results.

TABLE II.—SOUTH WALES COALFIELD : COMPARISON BETWEEN ACTUAL AND CALCULATED VOLATILE MATTER

Locality	Vertical distance in feet below top seam y	Volatile matter % of Upper seam	Volatile matter % of lower seam	Calculated volatile matter % of lower seam
1. Blaenavon and Varteg .	785	36·0	31·0	31·6
2. New Bridge and Crumlin	1,905	35·0	25·0	25·0
3. Bargoed .	2,365	29·0	17·5	17·9
4. Blaengarw .	2,055	26·5	17·0	17·2
5. Penrhiwceiber	1,478	19·5	13·2	13·7
6. Treherbert .	735	14·0	10·5	11·5
7. Resolven .	2,457	16·0	8·0	7·9
8. Abergelli .	800	14·2	10·8	11·4
9. Mynydd Carn Coch . .	410	13·0	12·1	12·0
10. Dulais . .	1,882 *	10·5	6·0	5·4
11. Gwindraeth . (Assumed dip zero plane 25°.)	805	5·7	4·9	4·0

Having clarified the position in regard to Hilt's " law " and Hilt's " rate " we may proceed with the main purpose of this article.

THE EXPONENTIAL EQUATION

To obtain a mathematical basis of comparison of coal substances we must first find the average volatile and fixed carbon percentages for a true coal at the end of the Carboniferous Period. Fortunately this is not so difficult as it sounds, for we may arrive at these figures first by obtaining the proximate analyses of Carboniferous coal seams in Britain which have been subjected to the minimum amount of orogenic pressure and then comparing them with the analyses of Tertiary coals which have not been subjected to any appreciable orogenic pressure or to magmatic heat.

* Hicks carried this vertical sequence to seams below the Brass Vein, and thus his depth for this sequence is given as 2,082 feet. This is a slip, the lowest seam worked at Cefn Coed Colly, Dulais Valley, on which this vertical sequence is based is the Brass ; lower seams have been transposed into the sequence from farther afield. O. T. Jones copies Hicks' data throughout.

Compression faulting is absent, and folding is broad in the Lower Carboniferous geo-syncline of Northumberland, in the Nottinghamshire and Derbyshire coalfield, and in the Warwickshire coalfields and these coalfields have the additional advantage of containing seams throughout thick sediments of the Carboniferous Limestone Series, throughout thick productive Coal Measures, and by contrast, throughout the thin productive Coal Measures of Warwickshire. Dealing first with the Lower Carboniferous coals of the Northumbrian geo-syncline, the coal substance (d.a.f.) figure of which were recently supplied by Dr. J. H. Jones and published (Great Britain, 1945) by the Ministry of Fuel and Power, we find that in the Scremerston Coal Group, some 5,000 feet below the base of the Coal Measures the coal substance figures are volatiles 48%, fixed carbon 52%. In the Shilbottle coal lying some 2,600 feet below the base of the Coal Measures the figures are volatiles 43% to 45%, fixed carbon 55% to 57%, and about 600 feet higher on the sequence the Little Limestone seam figures are volatiles 38% to 40%, and fixed carbon 60% to 62%. In passing it may be noted that in these thick Lower Carboniferous geo-synclinal measures of Northumberland we see yet another inversion of the so-called " law " of Hilt—the highest volatiles are at the bottom and the lowest volatiles at the top of the sequence. Furthermore this inversion persists for another 1,500 feet into the Upper Carboniferous where the volatiles of the seams of the productive Coal Measures, up to the High Main seam range from 37% to 41%. The inversion is partially rectified in the uppermost productive Coal Measures where the volatiles of the seams above the High Main range from 38% to 43%. Taking the full sequence of 7,000 feet of coal-bearing strata in the geo-syncline the extreme range of volatiles is 11% from 37% to 48%. Figures of a similar order are obtained from the productive Coal Measures of the Nottinghamshire and Derbyshire field (Dawe and Coles, 1948). Here the highest volatiles are 46% from the Black Shale seam, which is low in the sequence, but volatiles of the order of 42% are common throughout a sequence of 3,500 feet. Curiously enough the lowest and the highest workable seam of this sequence both give the relatively low volatile figure of 40% although stratigraphically 3,500 feet apart.

The figures quoted are of analyses made in the laboratories of the Coal Survey at one time under Fuel Research, but now transferred to the National Coal Board. Comparable Coal Survey figures for the Warwickshire field are not published, but are of the same order according to information received from Dr. Hall. The High Main, however, in the middle of the Coal Measures sequence, is exceptional in that the volatiles of this seam reach 51% ; other seams which reach 47% are the Thin above the Seven Feet, and the Deep Rider (D. A. Hall *in litt*).

The data from the three selected coalfields could be duplicated from other relatively undisturbed coalfields, but the particulars given above are sufficient to show that there is a pronounced though limited range in the volatile matter of the normal fat bituminous coals which are so prevalent in English coalfields outside the Armorican front. This range arises from differences in the original composition of the parent peat substance (which gave rise on coalification to vitrain, durain, etc.) and consequently in these fields the coal seam with the highest volatiles may occur at any horizon within the coal-bearing sequence. It is fortuitous that seams with the highest volatiles occur in the Carboniferous Limestone of Northumberland below 7,000 feet of coal-bearing strata with at one time a considerable additional thickness of Upper Coal Measures cover—of the order of at least 2,000 feet at Canonbie. Nevertheless, the occurrence of these very high volatile bituminous coals at such low stratigraphical levels in thick geo-synclinal Carboniferous Limestone sediments is one more proof that, for all practical purposes, devolatilization of coal seams cannot be related either to their former depth of burial by superincumbent strata or to geothermal gradients.

We may summarize by saying that good average figures for the coal substance of these Upper and Lower Carboniferous coals are : volatiles 43%, fixed carbon 57%. All three coalfields, however, are more or less folded, and thus they have been subjected to orogenic pressure and consequently it is to be expected that the coals have suffered some loss of volatiles since the end of Carboniferous sedimentation.

Turning to the youngest coals, the bedded Tertiary lignites, we find that their volatile matter (d.a.f.) approximates to 50%. In dealing with the European lignites Brame and King (1946) in their standard textbook on Fuels state : "The volatile matter in lignites falling within the above range [European lignites] is seldom less than 48%, it is usually in excess of 50%, but in a large number of cases the ratio of volatile matter to fixed carbon is approximately 1 to 1." This is in accord with the figures published in Bulletin 22 (1913) of the United States Bureau of Mines for North Dakota probably the best area in the western hemisphere to study unaltered lignites. Here in the Fort Union Formation of the Tertiary system there are 40,000 square miles of practically horizontal sediments containing brown woody lignites. Although in one or two cases the volatiles are as low as 42% the average volatile matter of the thirty-one analyses given in this Bulletin is 49·8% (d.a.f.) and, as in Europe, a large number have the ratio of volatile matter to fixed carbon of approximately 1 to 1.

Thus the average volatile figure of 50% for Tertiary lignites in Europe and in North America is only slightly higher than the figure of about 43% which we obtained from a study of Lower and Upper Carboniferous coals in three coalfields in England which, however,

have been subjected to relatively slight orogenic pressure. Such a slight difference in volatile matter between coals varying so widely in physical properties as brown lignites and bituminous coals may cause some surprise, and although the process of maturation of coal from woody lignite through sub-bituminous to bituminous coal is not the subject of the present paper, it may not be out of place to mention that unpublished work indicates that this rise in rank (brown lignite to bituminous coal) is caused essentially by loss of inherent moisture. A further rise of rank within the fat bituminous class is in part due to the same cause.

The 50% volatiles and 50% fixed carbon figures (d.a.f.) used as a basis in the calculations for South Wales coals which follow, cannot be far from the average values of the coal substance of British coals near the end of Carboniferous sedimentation. In the devolatilization of the coal substance it is the fixed carbon which remains constant, and the volatiles therefore should be expressed on the basis of 50% carbon. On this basis a coal substance of 30% volatiles and 70% fixed carbon has in effect, $\frac{30}{70} \times \frac{50}{1} = 21{\cdot}4\%$ volatiles, i.e. 100 grams of the original coal substance have been reduced to 71·4 grams by the elimination of 28·6 grams of volatiles.

The volatiles of the uppermost and lowest seams, in the eleven vertical sequences in South Wales which were utilized in the writer's previous paper to show progressive vertical devolatilization in South Wales towards the zero plane, are given below together with the directly comparable volatiles determined on the 50% fixed carbon basis.

TABLE III.—SOUTH WALES COALFIELD: COMPARISON OF VOLATILES: EMPIRICAL EQUATION

No.	Locality	Volatiles proximate analysis d.a.f. basis		Volatiles 50% fixed carbon d.a.f. basis	
		Upper Seam %	Lower Seam %	Upper Seam %	Lower Seam %
1	Blaenavon and Varteg	36·0	31	28·1	22·5
2	New Bridge and Crumlin	35·0	25	26·9	16·7
3	Bargoed	29·0	17·5	20·4	10·6
4	Blaengarw	26·5	17	18·0	10·2
5	Penrhiwceiber	19·5	13·2	12·1	7·6
6	Treherbert	14·0	10·5	8·1	5·9
7	Resolven	16·0	8·0	9·5	4·3
8	Abergelli	14·2	10·8	8·3	6·1
9	Mynydd Carn Goch	13·0	12·0	7·5	6·8
10	Dulais	10·5	6·0	5·9	3·2
11	Gwendraeth Valley	5·7	4·9	3·0	2·6

All the volatiles figures are markedly reduced in the last two columns of Table III and of necessity the function which controls their variation differs somewhat from that applicable in the empirical comparison of volatiles.

In the discussion of my previous paper Dr. Himus stated that the true relationship between volatiles and distance from the plane of the thrust must be expressed as a hyperbolic or as an exponential function (Himus, 1949). Without debating this somewhat abstruse point we may point out that the exponential equation:

$$v_2 = v_1 e^{-2 \cdot 8 \cdot 10^{-4} y \cos \theta}$$

satisfies all the known results, where v_2 and v_1 represent the volatiles (on the 50% fixed carbon basis) of the lower and upper seams respectively, y is the distance in feet of v_2 below v_1 and θ is the angle of dip of the zero plane [1] which in the earlier paper was determined as 5°. The calculated results using this equation are compared with the known results in the following table.

TABLE IV.—SOUTH WALES COALFIELD: COMPARISON BETWEEN KNOWN AND CALCULATED VOLATILE MATTER: EXPONENTIAL EQUATION

No.	Distance in feet below top seam y	Volatiles 50% Fixed Carbon basis		
		Upper Seam v_1	Lower Seam v_2	Lower Seam Calculated by Exponential equation v_2
1	785	28·1	22·5	22·6
2	1,905	26·9	16·7	15·8
3	2,365	20·4	10·6	10·5
4	2,055	18·0	10·2	10·1
5	1,478	12·1	7·6	8·0
6	735	8·1	5·9	6·6
7	2,457	9·5	4·3	4·8
8	800	8·3	6·1	6·6
9	410	7·5	6·8	6·7
10	1,882	5·9	3·2	3·5
11	805	3·0	2·6	2·4

As with the empirical equation original differences in composition give rise to a variation covered by a coal-type band (Trotter, 1949). Even so the calculated results compare favourably with the actual results and my mathematically minded friends should find cause for satisfaction in that the exponential equation gives results which are

[1] In this particular case cos θ approaches so near to unity that it could be virtually ignored. In other cases its value might have considerable influence on the results so for completeness the full equation is given.

possibly slightly more accurate than those obtained from the empirical equation. For normal purposes the latter will doubtless be used, but in calculations involving high ranking coals, where differences of the order of 1% or 2% are of importance in the commercial grading of anthracites, the additional arithmetic involved in using the exponential equation should prove to be well worth while. If we compare the results of the two equations it is seen there must be absolute coincidence of values at 50% volatiles. At the other end of the scale there is practical coincidence in the vicinity of zero volatiles. With the former equation an actual zero is attained ; with the exponential equation a theoretical zero is never reach d, but for practical purposes it is attained when the volatiles fall below 1%. The difficulty of estimating volatiles with any degree of accuracy in graphites and peranthracites, because of the presence of carbonates and/or pyrite in these deposits, is well known. One final word : both equations apply to the South Wales coals only.

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The Chalk Rock at Winterborne Abbas, Dorset [1]

By J. A. Robbie

Abstract

An abnormal lithological development of the Chalk Rock occurs in the neighbourhood of Winterborne Abbas, South Dorset, where it contains pebbles of Upper Greensand material. Two exposures of this rock have previously been recorded but further information regarding this variant of the Chalk Rock was obtained during the resurvey of the area in 1936. A possible source of origin for the derived material is suggested.

WINTERBORNE ABBAS is situated some 5 miles W.S.W. of Dorchester, on the road to Bridport, and near the village two exposures of an abnormal Chalk Rock were recorded by Barrois (1876, p. 87), Strahan (1898, pp. 188–190), and Jukes-Browne (1904, pp. 109–110). Of these two exposures the one at North Hill is still accessible but the other, in Kit Hill Bottom (see Text-fig. 1), is now grassed over.

In 1876 Barrois saw a conglomeratic band in the chalk exposed on the south-west side of North Hill and remarked that several of the pebbles were characteristic of the Upper Greensand, from which he inferred that erosion of the Cenomanian took place at the end of the Turonian.

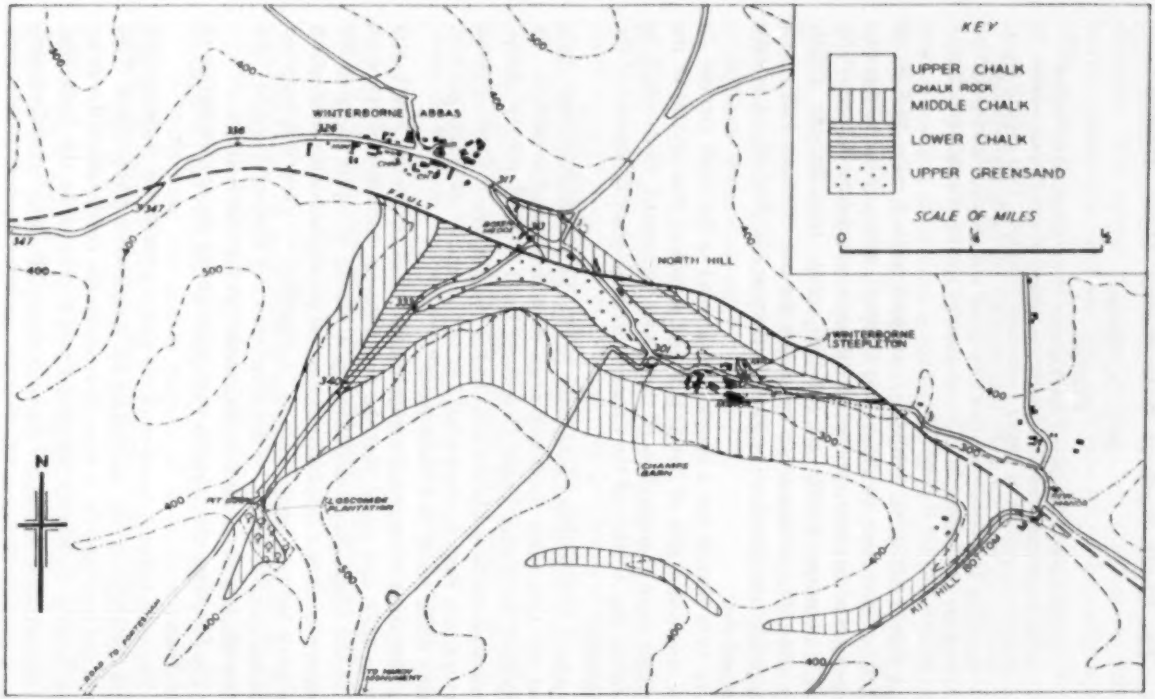
About 1889 Strahan noted at the North Hill Pit rough nodular chalk and soft glauconitic chalk with small rounded lumps like pebbles. He recorded the typical Upper Greensand fossil *Pecten* (*Neithea*) *quadricostatus* from the nodular rock. In Kit Hill Bottom he found exposed at the Chalk Rock horizon a bed 3 in. to 6 in. thick " of quartz-grit with many black grains in a chalk-paste ".

Jukes-Browne recorded conglomeratic chalk from the North Hill Pit in 1893, and noted that the conglomerate consisted of yellowish chalklike Chalk Rock embedded in a matrix of crystalline granular calcite as well as " small rounded inclusions of glauconitic sand which certainly have the appearance of ' a greensand ' ". He, too, recorded *Neithea quadricostata* from this green sand and also remarked on " the gritty chalk with quartz and glauconite " in Kit Hill Bottom.

The following observations were made during the reinvestigation of the district.

The main tectonic structure of the area is a low dome, fractured and with the northern part lowered by the Winterborne Abbas Fault. This fault can be traced for a short distance on the north side of the valley (see Text-fig. 1), but for the greater part it is found on the south side. At Winterborne Abbas the throw is about 200 feet, diminishing eastwards to about 80 feet at Martinstown, as shown by the fact that chalk

[1] Published with the permission of the Director, Geological Survey and Museum.



TEXT-FIG. 1.—Geological sketch-map of the Winterborne Abbas district.

of Planus Zone abuts on rock of not higher horizon than middle Lata Zone. To the west there is no evidence.

The dip of the Upper Chalk immediately north of the fault at Winterborne Abbas is 60° N. but flattens out to about 6° at Bradford Down, about 1½ miles E.N.E. of the village. South of the fault the beds dip much less steeply, the angle being never more than 10° S., decreasing to only a few degrees a short distance from the fault.

The pit on the west side of North Hill showed the following section :—

		Ft.
Breccia of flinty chalk, firm chalk, and flints (part of pit overgrown)	seen	10
Hard chalk with black flints and a flint band	about	20
Hard lumpy slickensided chalk		10
Blocky chalk with shattered bands of tabular flint		5
Firm blocky chalk, passing down into		13
Sandy glauconitic chalk		7
Hard siliceous chalk with calcite		4

A small fault has the effect of repeating the outcrop of the two lowest beds which constitute the Chalk Rock. For 28 feet above the 7 ft. glauconitic bed the chalk is of the Planus Zone, and the two beds at the top probably belong to the Cortestudinarium Zone. No pebbles of Upper Greensand were found nor were any notable fossils.

In a pit at the mouth of Kit Hill bottom hard siliceous chalk rests on siliceous chalk with quartz-lined cavities (Chalk Rock), then hard chalk with a ½ in. band of flint, and beneath this a gritty chalk with *Terebratulina* sp. Just east of this is the pit where Jukes-Browne (1904, p. 110) saw a similar section.

The road cutting down Kit Hill Bottom exposed the following section :—

		Ft.	*In.*
Chalk with glauconite		3	0
Inconstant layer of shattered flint			½
Band of quartz-grit in chalk paste			3 to 4
Siliceous chalk	seen		9

The quartz-grit contains small pieces of hard chalk and smoky flint (possibly Upper Greensand chert), glauconite, and subangular grains of quartz.

In Kit Hill bottom and westwards the chalk for a few feet below the Chalk Rock is usually hard and coarse and contains numerous large *Terebratulina* cf. *lata*. South of Winterborne Steepleton 5 feet to 6 feet of glauconitic chalk has been found below this coarse chalk.

Chalk Rock was again exposed on the Bridport–Dorchester road, west of Winterborne Abbas, where glauconitic chalk was dug in a temporary trench. Also, some 4 miles to the west of Winterborne Abbas, in a field about 250 yards N. of Litton Cheney Church, a hard

flaggy glauconitic chalk is exposed and about 3 miles W. of Winterborne Abbas, in the road leading north-eastwards past Long Bredy Church, Strahan (1898, p. 189) noted " a glauconitic chalk with flinty chalk above it, and a nodular rock with a few black flints below it " : he regarded this glauconitic chalk as corresponding to the glauconitic zone at Winterborne Abbas.

These exposures thus indicate the presence of glauconite and other material at or within a few feet of the top of the Middle Chalk.

Another important section was discovered about ¾ mile along the road to Portesham from Winterborne Abbas on the west side of the road. A good exposure of the abnormal Chalk Rock shows 2 feet of coarse chalk containing pebbles of hard flinty chalk and pieces of Upper Greensand. In the roadside a little south (i.e. further up the hill) are various exposures of soft marly glauconitic chalk and green sand. Much of the glauconitic chalk is above the conglomerate, and higher in the sequence flints appear, first in tabular form then as nobules.

A pit dug on the west side of the Portesham road showed that with the exception of the calcareous grit every member of the Upper Greensand of south-west England was represented as pebbles in the hard grey chalk. Glauconitic chalk, some of the pieces having yellow quartz-grains similar to those in the calcareous grit of the Upper Greensand, fairly well-rounded pebbles of glauconitic sand-rock, soft sandstone with *Exogyra obliquata*, and also coarsely rounded pieces of hard Exogyra Sandstone, and angular lumps of chert in various stages of desilicification. There were also several patches of soft glauconitic greensand, the largest being 6 inches thick and approximately 2 feet square, and found 7 ft. 2 in. from surface. Pebbles and pieces of hard greyish chalk and of hard siliceous chalk indistinguishable from normal Chalk Rock and numerous phosphatized pellets and fossils from the basal conglomerate of the Lower Chalk were also found. At a depth of 8 ft. 3 in. a tough grey chalk was encountered similar to that met with in a well 32 feet deep in Loscombe Plantation, on the east side of the road, although rock from the well contained rather more pellets and small pebbles of chalk. The fact that only the soft glauconitic sandstone fragments were well rounded while the more resistant sandstone and chert was less so, indicates a comparatively short journey for the derived material.

Fossils found in this pit proved to be a mixture of Albian and Cenomanian faunas, and the following (Rb 211–222, 239) [1] have been identified by Mr. Chatwin : *Chlamys* (*Aequipecten*) *asper* (Lamarck), " *Cyprina* " *quadrata* d'Orbigny, *Exogyra obliquata* (Pulteney),

[1] These numbers refer to specimens in the registered collection of the Geological Survey and Museum.

Inoceramus sp. *Pleurotomaria* cf. *dumorti* d'Archiac, "*Turbo*" sp., *Calycoceras* sp., *Schloenbachia* sp., *Turrilites acutus* Passy, and tooth of *Lamna appendiculata* Agassiz.

From the present evidence it is clear that at about Chalk Rock time an area of Chalk and Upper Greensand was being eroded. There is no evidence, however, of Chalk overstepping the Upper Greensand in the present outcrop of Chalk in Dorset. In looking for this erosion surface it seems reasonable to look to the west or south as these are the directions nearest the margin of the Chalk sea, and the material of the Winterborne variant of the Chalk Rock had not travelled far. Had the material come from the west traces of it would be expected in the Chalk Rock west of the Winterborne district, but the only indication in this direction is the glauconitic chalk at Litton Cheney and Long Bredy. To the south no evidence has been found of greensand material in the chalk, but for the greater part, zones well above the Chalk Rock are faulted against Jurassic rocks by the Ridgeway Fault, although in Bishop's Road, north of Abbotsbury, the Middle and part of the Lower Chalk are pellety, similar to the chalk from the well in Loscombe Plantation. In both these areas distinction between Middle and Lower Chalk is very difficult.

Thus, though there is no definite indication as to where erosion took place, in view of the evidence mentioned above and the proximity of the Weymouth Anticline to the south, movement and erosion on this axis in Chalk Rock time is suggested.

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The Position of the Laki Limestone in the Eocene Succession of Western Pakistan

By F. E. Eames

Abstract

It has previously been thought that in Sind the Meting Limestone-Laki Limestone succession was equivalent to the Bolan Limestone, and that argillaceous beds, which are occasionally developed above the Laki Limestone and below the overlying Khirthar, represented the Ghazij Shales. Recent evidence indicates that these higher argillaceous beds are the representatives of the Shales with Alabaster of the Western Punjab, that in Sind the Ghazij Shales are cut out at the Laki/Ranikot unconformity, and that the Meting Limestone-Laki Limestone succession represents calcareous horizons higher up in the Laki series than the Bolan Limestone.

WHILE carrying out investigations, during the period 1943 to 1947, into the classification and correlation of the Eocene of western Pakistan and western India, certain information having a bearing upon the position of the Laki Limestone in the Eocene succession has been obtained. Since it may be some time before the detailed results of these investigations are available, the writer feels that a brief review of the observations, in so far as they have a bearing upon the position of the Laki Limestone in the Eocene succession, may serve a useful purpose.

The Laki series was established by Noetling (1903) who gave (1905) the following succession in the Dharan Pass area (35 N/16, B. 1) :—

Spintangi beds (upper limestone group.)	6. Zone of *Conoclypeus alveolatus* Duncan and Sladen, and *Nummulites perforatus* (Montfort).
Ghazij Shales	5. Zone of *Anomia densistriata* Noetling. 4. Zone of *Cardita mutabilis* d'Archiac and Haime. 3. Zone of *Pugnellus sindensis* Noetling. 2. Nummulitic bed.
Laki beds (lower limestone group.)	1. Zone of *Macropneustes speciosus* Duncan and Sladen.

Since the publication of Noetling's work, the so-called Spintangi beds have always been considered to be of Khirthar age, and the known fauna indicates that this is unquestionably so. The zones of the Ghazij Shales are evidently taken from the succession further north in Baluchistan, where R. D. Oldham (1890) gave the name Ghazij beds to certain argillaceous strata overlying the Dunghan Limestone, in the valley which runs down from near the Dunghan mountain (29° 52′ : 68° 22°) to Spintangi (29° 55′ : 68° 8′). Although Noetling used the term Laki beds (spelt " Lakki ", according to old usage) in 1903, the type section must be in the Laki Range in which area he applied the term in the continuation of his work in 1905.

In discussing the stratigraphy of the Laki series (Lower Eocene)

of parts of Sind and Baluchistan, Dr. Nuttall (1925) gave the following succession in the area near Meting (40 C/4, B. 2) :—

	Feet.
Laki Limestone	200
Meting Shales	95
Meting Limestone . . .	140
Basal Laki Laterite . . .	25

Dr. Nuttall pointed out that, except for *Flosculina globosa* (Leymerie), the foraminiferal faunas of the Meting Limestone and of the Laki Limestone were identical. He considered that the break between the Laki Limestone and Meting Limestone was small, whereas that between the Basal Laki Laterite and the Upper Ranikot was large. Furthermore, he found that at the top of the Laki series along parts of the Laki Range the Laki Limestone was overlain unconformably by the Middle Khirthar, the Ghazij beds and Lower Khirthar of Baluchistan being absent.

Further detailed investigations into the classification and correlation of the Eocene in Western Pakistan and western India were initiated several years ago. The first task was the examination of a section along the Rakhi Nala (39 K/1, B. 1), west-south-west of Dera Ghazi Khan. Sections in the Kohat area and in Sind, and also in the Zinda Pir dome (39 J/7) have been examined since.

In the Rakhi Nala and Zinda Pir sections the following succession of Lower Eocene beds has been established :—

	Rakhi Nala. *Feet.*	*Zinda Pir.* *Feet.*
Shales with Alabaster	750	735
Rubbly Limestones	410	687
Green and Nodular Shales . . .	850	793
Ghazij Shales (Upper Rakhi Gaj Shales) .	1,620	1,815
Zinda Pir Limestone (upper part) . .	—	20–60

In this succession there are a few thin limestone bands near the base of the Upper Rakhi Gaj Shales, and these bands and the upper part of the Zinda Pir Limestone, to which they are probably equivalent, have yielded the form referred to in Western Pakistan as *Nummulites irregularis* Deshayes. This species appears to be restricted to the lower levels of the Laki series, having been found in such beds as the Nammal Limestone Shales of the Salt Range, in the Bolan Limestone and its equivalents in Baluchistan, and in limestones near the base of beds regarded as constituting the Laki series in the Kohat District. The bulk of the Upper Rakhi Gaj Shales overlying the limestone bands in the Rakhi Nala is believed on good grounds to be approximately equivalent to the Ghazij Shales ; both sets of beds overlie limestones containing *Nummulites irregularis* Deshayes. The Green and Nodular Shales and Rubbly Limestones contain a fauna which is very similar to that of the Laki Limestone and Meting Limestone of the Laki Range, and include, among other forms, a small variety of *Assilina granulosa* (d'Archiac). The Rubbly Limestones, especially those

of the Zinda Pir section where they are better developed, show a close lithological resemblance to the Laki Limestone as developed in the Bara dome at the northern end of the Laki Range. In the Rakhi Nala, the Shales with Alabaster have a poor foraminiferal fauna, but there are two horizons in its upper part which contain *Lituonella douvillei* L. M. Davies ; the molluscan fauna, while showing certain differences from the faunas of the beds below, contains many species in common and is obviously closely related to them. In the Bara dome the shales which occur above the Laki Limestone, and which Noetling referred to as Ghazij Shales, contain foraminifera of the *Lituonella-Coskinolina-Dictyoconus* suite in abundance in their upper levels. Furthermore, the same small variety of *Assilina granulosa* (d'Archiac) as occurs in the Green and Nodular Shales and Rubbly Limestones has been found in the lower part of these shales, as also a well-preserved specimen of *Cuspidaria lakiensis* Cox, which characterises the Shales with Alabaster, the Rubbly Limestones, the Green and Nodular Shales, and the uppermost two hundred feet of the Rakhi Gaj Shales in the Rakhi Nala. A final point of interest is that *Nummulites irregularis* Deshayes, which is of such common and widespread occurrence in the lower levels of the Laki series, has not been found in the foraminiferal faunas of the Laki beds developed in the Laki Range.

As a result of these observations, the writer concludes that the *Nummulites irregularis*-bearing horizons and most, if not all, the Ghazij Shales, or their representatives, are missing in the Laki Range, being cut out by the Laki/Ranikot unconformity, and that the so-called " Ghazij Shales " overlying the Laki Limestone are not the Ghazij Shales, but the representative of the younger Shales with Alabaster of western Punjab. The Meting Limestone-Laki Limestone succession is therefore not equivalent to the Bolan Limestone, but represents calcareous horizons considerably higher in the Laki series.

The writer is indebted to the Directors of the Burmah Oil Co., Ltd., for permission to publish this paper.

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The Origin of the Fenland Meres : Fenland Homologues of the Norfolk Broads

By J. N. Jennings

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Abstract

A section from the extinct waterway of the Little Ouse to the former Red Mere in west Suffolk is described, which shows that the lake marls succeed the clay flanges extending from the roddon silts. Thus the Fenland Meres formed in the course of the Coastal or Upper Silts transgression of the Fenland Basin, during which raised banks of silt were built along the tidal waterways, and these ponded back the fresh water. The Meres are shown to be roughly similar in age and manner of formation to the Norfolk Broads.

Of the outstanding problems of the postglacial stratigraphy of the Fenland, one of the most interesting is the age and manner of formation of the great medieval freshwater meres, some of which, such as Whittlesey Mere survived until the early nineteenth century (Godwin and Clifford, 1938A, p. 363). As a general rule the shell- and *Chara*-marls of the former lake beds lie beyond the limits of the Fen- or Buttery-clay of the earlier postglacial transgression of the Fenland Basin, but this is not so at the site of the former Ugg Mere, where the lake deposits overlie the Fen Clay, separated from it by an upper peat (Godwin and Clifford, 1938B, p. 344). In the western part of the Southern Fenland, however, Godwin and Clifford were unable to determine the stratigraphic relationship between the lake marls and the upper coastal silts of the later " Romano-British " transgression.[1] The roddon silts (Fowler, 1933, 1934), which extend landwards from the latter, were found to peter out before the most seaward mere, that of Benwick, is reached. This was unfortunate since a comparison of heights above O.D. and of pollen analyses suggested the possibility of

[1] It is not the purpose of this paper to discuss the exact age of the upper silts transgression, since this is a complex problem, bearing on which I have no fresh evidence to offer. Accordingly the designation " Romano-British ", employed in previous work, is retained here. G. Fowler (1949), however, maintains from the archaeological evidence that the major part of the transgression occurred before the Romano-British occupation of the Fenland silts in the first century A.D., though perhaps not long before ; less important were minor transgressions during and after the Romano-British occupation. There are many hut sites, e.g. in Elm parish, whose pottery shows continuous occupation from the first to the fourth centuries A.D., sealed by only 18 inches of silt at the most. On the other hand Godwin (1940B) has mustered the evidence for continued transgression ; investigations at Welney showed 6 feet of silt separating Romano-British occupation levels, Caster ware was found beneath 6 feet of silt in the excavation of the Roman bridge at Nordelph, and the siltbanks of the straight, artificial March roddon must have formed in Romano-British times. Further investigations are to be welcomed as opportunity offers.

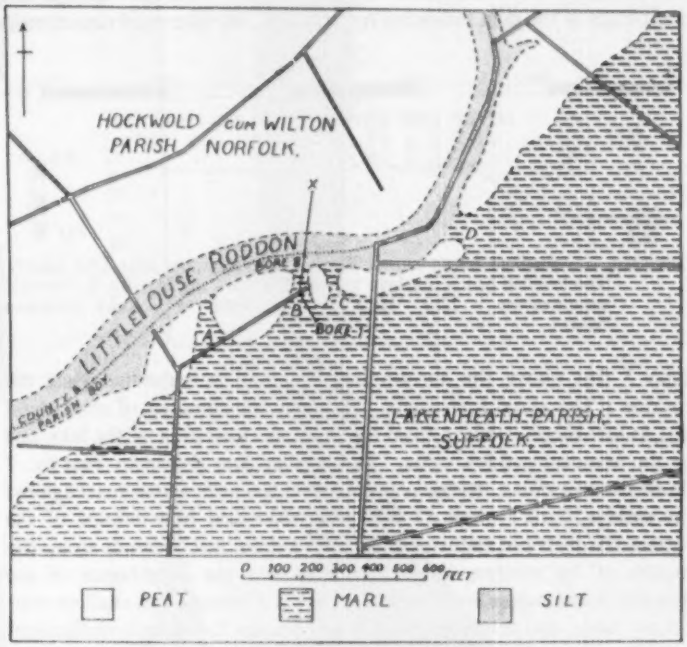
contemporaneity. The changes of pollen content, characteristic of the transition from Zone VII (Atlantic-Subboreal) to Zone VIII (Sub-atlantic) of the forest history of England and Wales, were found by

TEXT-FIG. 1.—Map of Redmere and Little Ouse Roddon. Drawn from Fowler (1947), p. 32, and an unpublished 6 in. survey by Fowler. Extinct lake bed and former waterway are stippled.

Godwin (1940A) in the peat immediately beneath both the lake marls and the upper silts. In view of this lack of evidence for lateral contact, two possible courses of physiographic development were discussed by these investigators. On the one hand, the Subatlantic climatic deterioration of the Early Iron Age may have resulted in extensive flooding by fresh water on the landward side of the Fens. On the other hand the cause of the formation of the meres may be sought in the marine transgression, which brought in the coastal- and roddon-silts. Godwin

and Clifford were inclined to consider that both factors might have been involved together.

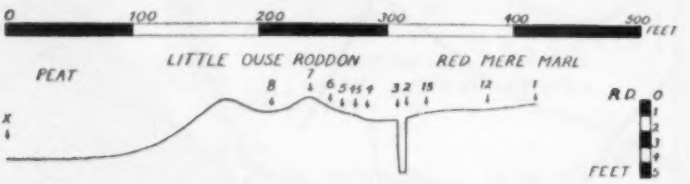
When, more recently, Fowler (1947) published some of his findings on the former Red or Reed Mere in the Sedge Fen district of West Suffolk, it appeared to the writer that the opportunity offered itself of obtaining evidence which might contribute to the resolution of this



TEXT-FIG. 2.—Map to show the former channels from Redmere to the Little Ouse near Old Decoy.

difficulty. Before the drainage of this, the next largest lake in England to Windermere, Red Mere extended near to the extinct natural waterway of the Little Ouse at a point a little upstream of the well-investigated sites of Peacock's and Plantation Farms. Indeed, for approximately 2½ miles the north-western margin of the lake marl runs near and roughly parallel to the Little Ouse roddon. Major Fowler kindly made available to me his 6 in. geological survey of the Burnt Fen Internal Drainage Board and this map, revealing three channels of marl linking the vast expanse of the Red Mere marl with the roddon silts, made it probable that the stratigraphic relation of these two most recent fenland deposits might be determined here (Text-fig. 1).

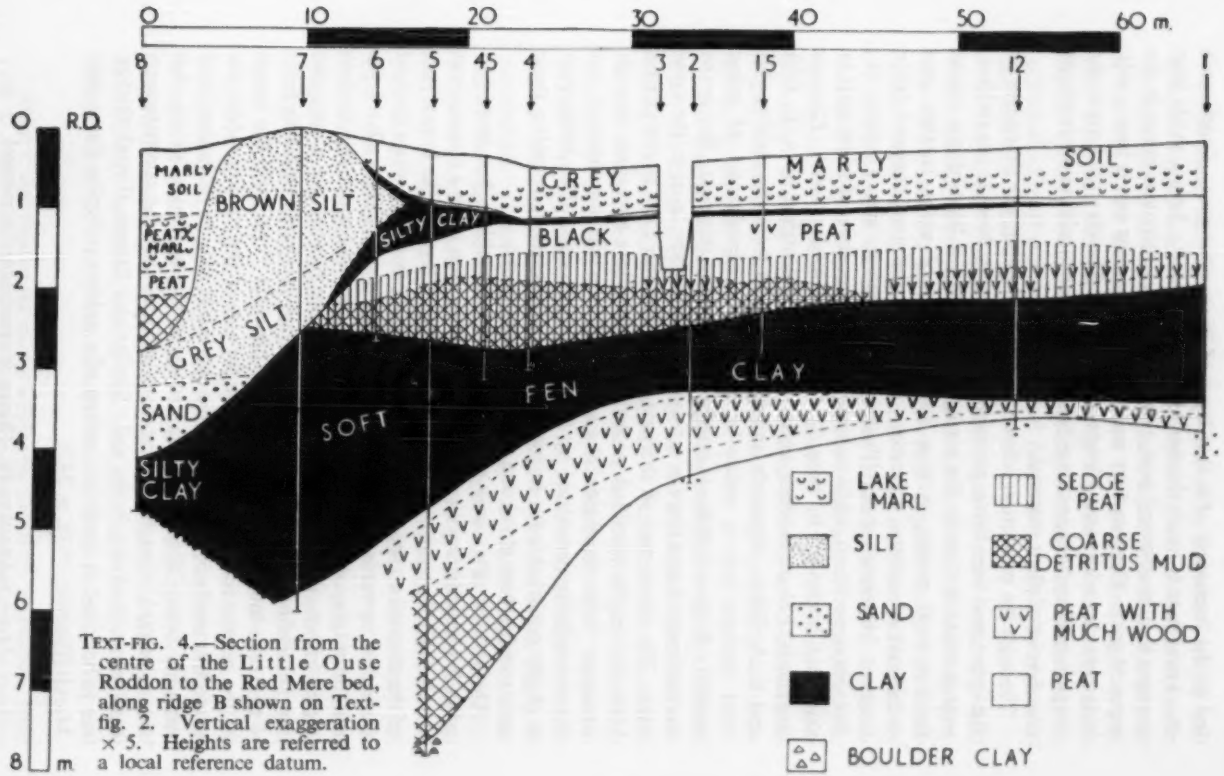
Text-fig. 2 shows in detail the disposition of these channels based on a 25 in. remapping of the area by the present writer. Since the deposits at the surface grade insensibly from one to the other as a result of ploughing it will be realized that a linear representation of the boundaries is bound to be somewhat arbitrary. Moreover, the limits change from year to year as peat wastage proceeds and silts and marls are ploughed downhill on to the peat areas. Through wastage and shrinkage of the peat following on drainage, the lake marl stands more



TEXT-FIG. 3.—Surface levels across Little Ouse Roddon near Old Decoy. The levelled line is marked × Bore 8–Bore 1 on Text-fig. 2. Vertical exaggeration × 12·5. Heights are referred to a local reference datum.

than 3 feet above the surrounding peatland hereabouts, while the roddon ridges stand higher still. Similarly the channels of marl stand out as low ridges running from the main elevated area of the lake bed to the adjacent roddon ridge. The levelled line shown in Text-fig. 3 illustrates this point. Ridge A (Text-fig. 2) has only a little marl against the roddon flank ; ridge D is the broadest and best defined of the former channels but unfortunately a deep drain has been cut along the middle of the roddon where it adjoins and the disturbance of the deposits is correspondingly great ; C is but a narrow and shallow subsidiary ridge, and therefore ridge B was chosen for close investigation.

In Text-fig. 4 are represented the results of a close-set line of bores from the margin of the main area of Red Mere along ridge B to the central hollow and former channel of the Little Ouse roddon. In this section the lower peat of the Southern Fenland is best developed in bore 5, which reaches down into what is most probably the Late Glacial or Preboreal channel of the Little Ouse. Here are nearly 2 m. of black-brown or grey-brown silty coarse detritus mud, with frequent freshwater shells. The following species were kindly identified by A. E. Ellis and E. A. Ellis : *Acroloxus lacustris, Bithynia leachii, B. tentaculata, Limnaea auricularia, L. peregra, Physa fontinalis, Pisidium amnicum, P. nitidum, P. subtruncatum, Planorbis albus, P. contortus, P. crista, P. vortex, Segmentina complanata, Valvata cristata, V. piscinalis.* This mud passes upwards into a highly humified dark brown peat with abundant wood. At the top wetter conditions



TEXT-FIG. 4.—Section from the centre of the Little Ouse Roddon to the Red Mere bed, along ridge B shown on Text-fig. 2. Vertical exaggeration × 5. Heights are referred to a local reference datum.

led to the formation of a thin layer of *Phragmites* peat. Southwards this lower peat is much thinner and rests on sand ; here a sandy peat changes to a brushwood peat, while *Phragmites* rhizomes occur in the topmost part. The Fen Clay seals in this lower peat and is here a soft, blue-grey clay with some *Phragmites* remains. The clay thickens in the deep channel and in bore 8 has become a silty clay, with sandy horizons and devoid of plant material.

Through the protection offered by the marl cover, the characters of the upper peat were better preserved than is usual. Near to the roddon, over a slight hollow in the surface of the clay, a light-brown coarse detritus mud occurs, with a large content of sedge rootlets and occasional *Phragmites* rhizomes. In bore 4 the mud contains fairly frequent freshwater shells (*Pisidium* sp., *Planorbis* sp., *Limnaea* sp., *Bithynia tentaculata*), while in bore 5 there are pockets of white marl in this mud horizon. In bore 2 it yielded *Bithynia leachii*, *Limnaea truncatula*, *Valvata cristata*, and *V. piscinalis* (identified by A. E. Ellis and E. A. Ellis). Upwards and laterally away from the roddon this mud changes into a yellow-brown peat, predominantly of sedge rootfelt. In bore 2 *Bithynia* opercula occurred in this peat. But in the southernmost bores there is a pronouncedly woody layer in the same peat. The upper part of the peat above the Fen Clay is everywhere black and highly humified, probably by secondary alteration through drainage. What its original characters had been was not apparent, but it is secondarily penetrated by *Phragmites* rhizomes. This black peat is chiefly remarkable for its inclusion of white gypsum crystals ; these are most frequent along and within the rhizomes.[1]

The roddon silts come next in order of deposition, but there had preceded (possibly by very little) a phase of erosion when a channel was cut through the upper peat and into the Fen Clay. In the lowest part of the channel a grey silty sand was laid down, but there was a gradual transition upwards through grey silt to the usual brown silt of the roddon ridges. Away from the ridge, the silts wedge out rapidly into a grey-brown, silty clay. By bore 4 this flange has become a very thin but well-defined horizon of grey-brown clay, varying in thickness from 4 to 8 cm. and extending to bore 12, which is 55 m. from the crown of the nearest roddon ridge. On the far side of the roddon, where the protective marl cover is absent, this clay could only be recognized with certainty some 20 m. from the crown of the roddon ridge on that side ; beyond, ploughing must have incorporated the comparatively small amount of clay in the soil. Similar clay flanges, though thicker, are to be found in Godwin's section of a roddon at Poplar Farm, near March (Godwin, 1938, p. 242).

[1] I am indebted to Dr. Harvey for analysing this mineral.

White marl, with freshwater shells (including *Limnaea peregra* and *Bithynia tentaculata*), overlies this clay extension from the roddon, for the most part separated from it by a black, highly humified, fissile peat a few cm. thick at the most. Above the undisturbed marl is the grey marly soil derived from it. In this instance the marl ridge abuts against the steep outer slopes of the brown roddon silts themselves, the undisturbed marl occurring in bore 6 but 4·6 m. from the crown of the adjacent roddon ridge.

In the central hollow of the roddon (bore 8) were found the final river channel deposits of the natural Little Ouse. Above the grey silts of the roddon comes a greenish-grey organic mud, with freshwater shells and a slight silt content. The molluscs, identified by A. E. Ellis and E. A. Ellis, were of the following species : *Acroloxus lacustris*, *Bithynia tentaculata*, *Pisidium amnicum*, *P. cinereum* var. *ponderosa*, *P. henslowaricum*, *P. nitidum*, *P. pulchellum*, *Valvata piscinalis*. A black, mouldered peat detritus follows, to which succeeds a grey-brown marl, with peaty inclusions. Marly and peaty soil completes the channel fill.

This section agrees in general with the composite section derived from the Shippea Hill investigations of the Fenland Research Committee (Godwin and Clifford, 1938A, p. 379), but in addition it provides definite evidence of the relationship between the former mere bed and the extinct waterway of the roddon. Undoubtedly the " Romano-British " transgression had achieved its maximum horizontal extent here in the form of the thin clay horizon before the marls began to accumulate.[1] Nevertheless, the latter may well have begun to form before the tides had ceased to bring up estuarine silt to raise the banks. There is good reason then to regard the mere as due to the ponding back of fresh water behind the raised silt banks, which hindered its escape. Evidence is lacking as to whether this effect may or may not have been influenced by climatic change.

Attention has been drawn to the similarity between the former Fenland meres and the Broads of east Norfolk (Godwin and Clifford, 1938A, p. 396). Both systems of shallow lakes are found in inland peat areas or " sietland ", behind a coastal region of mineral alluvium or " hochland ". Fowler's later mapping has given more support to this comparison. The manner in which the Little Ouse roddon runs close to the Red Mere bed but remains separated from it, apart from a few narrow channels, by a strip of peat (partly overlying the clay flange of the roddon), resembles closely the hydrographic pattern of the Bure valley, where the river winds between broads lying on either side, and

[1] Ridge C also showed the marl overlying the clay from the roddon. Near ridge D a great deal of marl was exposed in the central drain in the roddon.

where lake and stream are linked by a few " gatways " across the separating " ronds ". Previously it had been recognized that Ramsay and Benwick Meres were to be likened also to this lateral or by-passed type of broad, such as Wroxham or Salhouse Broad, since these meres lay off the medieval course of the Nene. Willingham and Streatham Meres seem to have had similar relationships to the Ouse and Granta respectively. Soham Mere, by contrast, must be compared with the broads which occupy tributary valleys, such as Hickling Broad.

That this similarity extends beyond the facts of arrangement and nature of the lake basins to the mechanism of formation, may perhaps be demonstrable now. Investigations still in progress have shown that the Norfolk Broads were formed in the course of an estuarine transgression, which took place after the inception of the forest changes which fall into Transition Zone VII–VIII. This transgression involved the filling of the seaward parts of the east Norfolk valleys with soft, blue-grey clay to a considerable thickness over peats. But upstream the clay extended inland only as a deep, clay-filled channel cut into peats, with low clay banks extending laterally as flanges from the top of this channel. Between these clay banks (which underly the present-day " ronds ") and the upland slopes, fresh water was ponded to form the broads. Since the transgression ended, *Phragmites* peat has accumulated on the clay banks to complete the enclosure of the broads and to isolate them from the main waterways. In the broads basins, organic nekron muds have accumulated. If the middle Bure valley were intensively drained, the peat of the ronds would eventually waste away to expose the clay banks. These would gradually begin to stand out like the Fenland roddons, except that they would be broader and flatter. This would be inevitable since the Broads' gyttjas would continue to shrink and waste away, falling in surface level, except where they were heavily calcareous. The comparison, then, with the Norfolk Broads strengthens the case put forward on the basis of the Red Mere section that the Fenland Meres were formed as a consequence of the later postglacial transgression, that of Zone VIII of the forest history. These shallow lakes lay in the flat hollows between the natural embankments of the tidal waterways and the upland margin ; it was with great difficulty that fresh water could escape from these depressions. Thus recognizing the extinct Fenland Meres as close homologues of the Broads, the possibility suggests itself that other fossil counterparts of the latter may yet be determined through the study of the alluvial deposits in such areas, for example, as the Ancholme valley.

I thank Major G. Fowler for so generously lending me his unpublished maps and for practical help in other directions. I am grateful to him and to Dr. H. Godwin for criticizing the manuscript of this paper.

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CORRESPONDENCE

HILT'S LAW AND THE VOLATILE CONTENTS OF COAL SEAMS

SIR,—Jones (*Geol. Mag.*, lxxxvi, 1949) makes the primary assumption that the differences in the volatile contents of evenly spaced seams in any vertical sequence is the same irrespective of the ranks of the seams. The difference in volatile content of seams 1,000 feet apart is termed the " Hilt Rate ". This assumption is based on a least squares study of short vertical sections in South Wales and in Kent that show a uniform rate of decrease to be slightly (but not significantly) more probable than more complex relationships that allow for a decrease in the Hilt Rate with depth and increasing rank. Having made the assumption that a uniform rate of decrease is normal, Jones is faced with explaining the low rates shown by high rank sections. This he does by assuming that pressure inhibits coal metamorphism. But in spite of the evidence from least squares, if pressure is important the Hilt rate cannot be uniform, but must decrease with depth. No other evidence exists that the rate of decrease of volatile matter with depth is constant, and indeed this simple relation does not agree with the available experimental results on the decomposition of coal with progressively increasing temperature at atmospheric pressure. An increase in pressure will no doubt cause the volatile contents at the corresponding temperatures to differ, but it is unlikely to make the relationship as simple as Jones assumed it to be. If the Hilt Rate is assumed to decrease with depth (and rank) no reason then exists for postulating that pressure inhibits coal metamorphism. It may well have the opposite effect. If the Hilt Rate varies with rank, metamorphic gradients in sections with different ranges of coal ranks cannot be directly compared by their Hilt Rates. In the Kent Coalfield, however, the ranges in ranks are similar and the differences are real, irrespective of what kind of rate of change with depth is accepted. Jones considers the differences to be related to differences in rates of subsidence during the final phase of sedimentation (sediments now eroded). With this I am in full agreement, but I cannot agree with Jones that the different Hilt Rates are due to diffusion of volatiles being so slow that diffusion was appreciably affected by these different rates of subsidence. If this were the case, the porosity of enclosing sediments should in general control coal rank. Coal lenses in sandstone should be of higher rank than those in mudstone ; thin seams should be of higher rank than thick ones. I know of no evidence for this. As an alternative, I suggest that the final phase of sedimentation was so rapid that the sediments accumulated more rapidly than they were warmed up by the internal heat of the earth, and that this caused the iso-geotherms to be more widely spaced in the rapidly subsiding central part of the Kent geosyncline than at the margins. If coal

rank depended on maximum temperatures then the analytical data fit this simple explanation as well as they do the more complicated one proposed by Jones. It has the additional advantage that a quantitative test is possible if the rate of final subsidence and duration of deepest burial can be estimated.

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GREYMOUTH,
NEW ZEALAND.
January, 1950.

COELOTEUTHIS AND SYNONYMOUS HOMONYMY AT GENERIC LEVEL

SIR,—Dr. Otto Haas recently pointed out in the *Journal of Paleontology* (1949, vol. 23, pp. 573–4) the theoretical possibility of synonymous homonyms (or homonymous synonyms). Still more recently, Dr. D. L. Frizzell, in the same *Journal* (1950, vol. 24, p. 117), has given actual examples of synonymous homonyms at specific level, though commenting that the independent proposal of two identical names for a genus would be an unusual phenomenon. It may therefore be of interest to draw attention to an instance with which I have long been familiar of synonymous homonymy—indeed, objectively synonymous homonymy—at the generic level.

The genus *Coeloteuthis* was proposed by Marcel Lissajous in " Toarcien des environs de Mâcon ", *Bull. de la Soc. d'Hist. Nat. de Mâcon*, 1906, p. 265. This paper is probably not in any library in England, but Professor Jean Goguel, of the Service de la Carte Géologique de la France, has found it for me in the library of the Société Géologique de France, and has kindly had made for me a typewritten copy of the part relating to belemnites. For our present purpose the essential statement is : " *Genre COELOTEUTHIS* nov. gen." . . . " Le type de ce genre est *Belemnites excavatus* Phillips." Further references to *Coeloteuthis* Lissajous were made in 1915 by Lissajous himself (" Quelques remarques sur les Bélemnites jurassiques ", *Bull. de la Soc. d'Hist. nat. de Mâcon*, 1915, p. 13, of which there is a reprint in the Department of Geology of the British Museum), and by P. Lemoine (*Revue critique de Paléozoologie*, 19th year, No. 4, 1915, p. 157).

In 1919, however, Professor E. Stolley (11. *Jahresbericht d. Niedersächsischen geol. Vereins zu Hannover*, 1919, pp. 37, 39) independently proposed the genus *Coeloteuthis*, with type species *Belemnites excavatus* Phillips. Perhaps the possibility of a subconscious recollection cannot be wholly excluded, but it seems more likely that Professor Stolley had not seen the relevant publications of Lissajous, probably not easily accessible in Germany at the best of times ; moreover, unawareness of the 1915 publications might well have resulted from the interruption of free communication by the war of 1914–18. Whatever the explanation, the result is that *Coeloteuthis* Stolley is an objectively synonymous homonym of *Coeloteuthis* Lissajous.

Consideration of the synonymy of *Coeloteuthis* involves also the question of the relationship between *Coeloteuthis* Lissajous and *Clastoteuthis* Lang (*Quart. Journ. Geol. Soc.*, lxxxiv, 1928, pp. 196–7). The type species of *Clastoteuthis* is *C. abrupta*, of which the holotype, registered C28864, and various paratypes, are in the British Museum (Natural History). Dr. Lang considered *Coeloteuthis* and *Clastoteuthis* to be very different genera, referring them respectively to the Coeloteuthinae and Passaloteuthinae as delimited by Professor Naef (1922, *Die fossilen Tintenfische*, pp. 224, 229, 230) ; but Dr. Lang had not seen the type material of *Coeloteuthis excavata*. Phillips has described and figured (*Palaeont. Soc. Monog. Brit. Belemnitidae*, pp. 37–8, and pl. II, fig. 4) two syntypes of *Belemnites excavatus*. The original of fig. 4 S cannot, indeed, be found ; judging from the figure, it is a non-median section liable to be misunderstood. In 1930, however, I succeeded in recognizing, in Oxford University Museum, the original of fig. 4 *v*, *l*, *s'*, *s''*, which is hereby chosen as lectotype of the species. This specimen, since registered J1193, has

been sent to me on loan through the kindness of Mr. J. M. Edmonds, of Oxford. It has the usual belemnite structure of radiating prismatic fibres and concentric growth-layers. Dr. F. C. Fraser, of the British Museum Zoological Department, has kindly had taken for me X-ray skiagrams, in one of which the profile of the infilled alveolus of this specimen can be faintly seen; the alveolus proves to occupy more of the guard than is usual in *Clastoteuthis*, but less than authors have supposed it to occupy in *Coeloteuthis*. The apex of the alveolus is about 7 mm. from the apex of the guard and, as in the *Clastoteuthis* type-material, is fairly eccentric; it is about 3·8 mm. from the nearest point on the venter and about 6·8 mm. from the nearest point on the dorsum. As compared with the type-material of *Clastoteuthis* the alveolar part of the guard tapers unusually rapidly, whilst the apical region seems to have been unusually short and blunt, even before the slight erosion of the apex that has accentuated its bluntness. I am satisfied, however, that although the lectotype of *Coeloteuthis excavata* is an extreme form it represents the same genus to which Dr. Lang later applied the name *Clastoteuthis*, and that this must therefore be considered a synonym of *Coeloteuthis*. Whether separate sub-families Coeloteuthinae and Passaloteuthinae should be recognized or not, there seems no justification for drawing a distinction between them on the basis hithrto adopted.

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26th April, 1950.

PRE-CAMBRIAN FORMATIONS OF INDIA

SIR,—The very interesting letter on this subject by Sir Lewis Fermor (*Geol. Mag.*, lxxxvii, 1950, p. 140) raises a great many points for discussion, but as most of these will sooner or later be settled by the acquisition of appropriate data it would be out of place here to indulge in a lengthy expression of personal opinions. The essential difference between Sir Lewis and myself arises from the fact that I am trying to recognize Pre-Cambrian orogenic belts, and to date their closing stages from investigations of their radioactive minerals, whereas he is trying to correlate formations and sequences of formations: a very different proposition.

One point, however, calls for immediate attention, since it involves an error of fact which I regret having made and am glad to see corrected. Referring to my paper (*Geol. Mag.*, lxxxvi, 1949, p. 290), Sir Lewis writes: "The strike direction shown on Professor Holmes' map in Text-fig 1 marked 'Satpura Range' does not represent any strike of the older rocks, as these are here covered by the Deccan Trap." Looking into the source of this mistake I find that I traced the position of the Satpura Range from the orographical map of India in *The Oxford Advanced Atlas* and then went on to assume that it also represented the position of the Pre-Cambrian rocks of the Satpura Range described by Crookshank (*Mem. Geol. Surv. India*, 56(2), 1936). Actually, the latter lie far to the east of the position marked on my map. It follows that on present evidence there is no proof that the Aravalli orogenic belt is older than the Satpura belt; it could just as well be a continuation of the latter as of the Dharwar belt and, of course, it may be neither. Unfortunately, no radioactive mineral suitable for age determination has yet been recorded from the late Aravalli pegmatites.

While the Aravalli problem must remain unsolved for the present, that of the Nellore mica belt should soon be cleared up. A new analysis of Nellore samarskite by Professor P. B. Sarkar gives a crude age of 1760 m.y. and lead from this mineral is being isotopically analysed by Professor Nier. Work is also beginning on radioactive minerals from rocks belonging respectively to the Dharwar and Eastern Ghats belts. The results of the three investigations should make it possible to date these belts and also to show whether the Nellore pegmatites are of late Dharwar age or not.

In reference to the desirability—emphasized by Sir Lewis—of dating the Cuddapah System in its type area, I can only suggest an application of the helium method to a concentrate of black ores, such as titaniferous magnetite, separated from the post-Cuddapah dolerites (cf. Hurley and Goodman: *Bull. Geol. Soc. Am.*, 54, 1943, p. 305). It should not be overlooked that Dubey (*Nature*, 126, 1930, p. 807) applied the helium method to a basalt flow from the upper part of the Gwalior Series and obtained an "age" of about 500 m.y. Since the helium method yields only minimum ages, except for the feebly radioactive black ores, the Gwalior Series may reasonably be assigned to the Pre-Cambrian. It is worth noticing, however, that Dubey's work on the Whin Sill and the Cleveland Dyke, carried out by the same methods (Dubey and Holmes: *Nature*, 123, 1929, p. 794), gave "ages" that are only a little lower than those now regarded as most probable. This consideration supports the view that the Gwalior Series is more likely to be of late Pre-Cambrian age (say, 550–600 m.y.) than of Aravalli age (900 m.y. or more). The traditional correlation of Gwalior with Cuddapah is therefore at least consistent with the limited evidence available; obviously, however, its validity remains to be proved. I hope to co-operate with Sir Lewis in making practical arrangements for carrying out the suggestion for settling the age of the Cuddapahs.

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5th May, 1950.

BATHONIAN *VIVIPARUS*-LIKE GASTROPODS

SIR,—Dr. T. C. Yen's proposition of a new generic name *Bathonella* for *Viviparus*-like gastropods found in Bathonian rocks in England, Scotland, and France has given rise to an interesting controversy, to which Mr. Hugh Watson has been the latest contributor.[1] Two points are at issue. Did these gastropods live in fresh, brackish, or fully salt water? Are they so completely indistinguishable from *Viviparus* that they could belong to no other genus, whatever their habitat? It should be possible to answer the first question by considering all relevant evidence as to the conditions of formation of the deposits in which they are found, for it seems rather unreasonable to suggest that every occurrence is to be explained by transportation by rivers in flood or some such accident. Apart from their presence in the Sharp's Hill Beds of N. Oxfordshire, associated at one locality with marine shells, they have been found at several horizons and localities in the Great Estaurine Series of Skye. Mr. F. W. Anderson (who is convinced from familiarity in the field that the beds containing these shells are not of freshwater origin) has kindly sent me a full list of the occurrences in that island (apart from the one recorded in Dr. Yen's paper) and of the associated fossils. The list is summarized below; the records are all Mr. Anderson's except for two published by Tate, whose generic determinations have been revised. The beds are cited in descending order.[2]

e. *Ostracod Limestones. Bathonella* has been found at seven localities, associated at one with *Protomiodon* spp. and "*Estheria*", at a second with *Protomiodon* and ostracods, at a third with *Hydrobia praecursor* and "*Estheria*", at a fourth with *Quenstedtia staffinensis*, ostracods and "*Estheria*", at a fifth with ostracods and "*Estheria*", and at the other two alone.

[1] *Geol. Mag.*, lxxxvii, 1950, 17–25.

[2] For a summary of the succession in Skye and a revision of the fossil determinations of previous authors, see F. W. Anderson and L. R. Cox, *Proc. R. Phys. Soc. Edinb.*, xxiii, (2), 1948, 103–122.

d. *Lower Ostrea Beds.* At one locality with *Protomiodon* ; at Loch Bay with *Neridomus arata, Neridomus staffinensis, Zebina caledonica, Ostrea hebridica, Protomiodon brycei, Anisocardia cucullata,* and *Pleuromya robusta* (Tate's record).

c. *Concretionary Sandstone Series.* At one locality in abundance at the base of a 13 ft. bed full of *Protomiodon* spp. ; at a second locality alone.

b. *Estheria Shales.* At one locality with *Protomiodon,* " *Estheria* ", and ostracods (the shales contain algal beds and *Ostrea*) ; at Eist with *Cylindrobullina inermis, Ostrea hebridica,* and *Protomiodon cunninghamii* (Tate's record).

a. *White Sandstone.* With *Protomiodon.*

From these records it appears that the most frequent associate of *Bathonella* is *Protomiodon.* Other associated forms are *Hydrobia* and " *Estheria* ", both of which could be of fresh or brackish water origin ; *Quenstedtia staffinensis,* an apparently marine form ; several marine species, according to Tate's records (but it might be maintained that these were probably not collected from exactly the same bed), and ostracods. The ostracods will naturally have an important bearing on the question ; Mr. Anderson tells me that their study is not yet completed, but so far there is no evidence of freshwater genera among them. Mr. Watson cites *Protomiodon* as evidence of freshwater conditions. The following, however, are those occurrences in other areas for which I can vouch personally :—

(1) Upper Estuarine Series of Rutland and Lincolnshire. The associated forms are *Eomiodon fimbriatus* (Lycett) and *Cuspidaria ibbetsoni* (Morris), both found also in beds of more purely marine facies.

(2) Shales above Millepore Bed at Yons Nab, Gristhorpe Bay, Yorkshire. Besides *Protomiodon concentricus* (Bean), these contain plant remains, but also abundant *Trigonia* (Mr. P. C. Sylvester-Bradley, *in lit.*).

(3) " Bathonien saumâtre " of the Moulinets mine, Dourbie valley, Causses du Larzac, France (*P. ruthenensis* (Gourret), redescription in course of publication by Monsieur P. L. Maubeuge and myself). The associated species, in the same hand-specimens, are *Nerinella* n. sp. and *Naricopsina matheroni* (Gourret), both marine forms.

Clearly, therefore, *Protomiodon* cannot be cited as evidence of freshwater conditions, and the earliest recorded occurrence of its successor, *Neomiodon,* is in the marine Sables de Cordebugle of the Corallian beds of Normandy. Mr. Watson cites *Corbicula* as a freshwater genus found in Bathonian rocks and " known to have been common in Jurassic times ", and remarks upon the improbability of marine forms coming to resemble it. He is, doubtless (as required by the rules of nomenclature), using this name for the genus more familiarly known as *Cyrena,* ignoring the fact that the Jurassic shells referred to it by early authors are (with a few exceptions) precisely those now included in *Neomiodon* and *Protomiodon* on account of their very different cardinal dentition. In the paper by F. W. Anderson and myself already cited it is shown that a few other supposed species of " *Cyrena* " from the Great Estuarine Series actually belong to the marine genera *Astarte, Anisocardia,* and *Eocallista.* Far from having " been common in Jurassic times ", *Corbicula* (*alias Cyrena*) did not make its appearance until late in the Cretaceous.

The evidence suggests that the Scottish beds in which *Bathonella* occurs were deposited in brackish water, inhabited at times by marine forms which (like many modern ones) could tolerate diminished salinity. It is interesting to note that Mr. Watson, after maintaining that its occurrence fossil with marine species may have been due to one of several circumstances, but not to association during life, finally admits the possibility of a brackish-water origin for *Bathonella.*

The second question, whether morphological similarities demand the reunion of *Bathonella* with *Viviparus* even admitting that it probably did not

live in fresh water, is none too easy to answer. Unfortunately, the general morphology of a gastropod shell, in the absence of knowledge of the soft parts, operculum, and radula, is not always an infallible guide to its affinities. Besides the marine species which I mentioned in my previous letter there are, for example, members of the Palaeozoic family Trochonematidae which are remarkably similar to *Viviparus*. The figures published by Mr. Watson show the general similarity between *Bathonella* and *Viviparus* which led Hudleston and Cossmann, before him, to regard them as identical, but at the same time they bring out differences in the outline of the earlier spire whorls and (less clearly) in that of the posterior end of the aperture which I considered might justify Dr. Yen's generic distinction. It could, of course, be maintained that these differences are specific and not generic, but as the mere mention of the genus *Viviparus* suggests freshwater conditions, the generic distinction seems all the more desirable.

Textbooks[1] tell us how the freshwater and terrestrial mollusca were derived from marine forms by gradual invasion of new habitats, beginning (in the first case) with brackish water. The affinities of a supposed *Viviparus* (*V. garwoodi*) from Lower Carboniferous beds seem very doubtful. It may be that in *Bathonella* we have a derivative of the marine family from which the Viviparidae sprang, caught in the first stage of this invasion.

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Sir,—Since my paper "On some Bathonian Mollusca from Skye" was published, the problem whether a *Viviparus*-like group of gastropods found in the Bathonian beds, and for which I have proposed the name *Bathonella*, is of marine or freshwater origin has arrested the attention of several palaeontologists, one zoologist, and one anatomist. As this problem is of fundamental importance, their comments are welcome, and my appreciation goes as much, if not more, to those who oppose my interpretation that this group of gastropods is of marine origin as to those who accept it. Recently somewhat misleading comments on the subject have come to my attention, and it is necessary to discuss the matter further to help clarify the issue.

Before considering details, two important points should be noted. First, my generic description of *Bathonella* and the supplementary notes should be taken as a whole; if a description is broken into fragments and each is cited at convenience, the basic facts are bound to be distorted.

Secondly, to study the problem objectively the geological criteria pertaining to the fossil-bearing beds, including lithology and other like evidence of conditions of deposition, should be borne in mind, in addition to the morphology of the fossils and the assemblage of the organic remains.

On morphological grounds I maintain that my original description of *Bathonella* is complete (including "acutely conical spire", "aperture . . . barely attaching to the preceding whorl", "lines of growth . . . distinctly curved towards the base", etc.), and that it describes a genus which is readily separated from *Viviparus* Montfort. It is possible to detach the reference to a naticoid feature, or any other single character, from the description to argue for the opposite conclusion, but that is to destroy the unity of the generic characters. It is not permissible to build up an argument by taking one feature from a description to match that of a living species in North America, another feature to match that of species now existing in Africa, still another feature to match that of a species of Jurassic age in England, and then on the basis of such morphological resemblances to draw a conclusion that "the characters of the shell seem to afford little justification for placing in a separate genus . . .".

[1] Cf. A. H. Cooke, "Molluscs," *Cambridge Natural History*, iii, pp. 11–14 (1895).

My illustrations had to include figures of specimens in different states of preservation. The feature of an almost detached parietal wall is not well preserved in every specimen, and it cannot, therefore, be shown in every figure. My descriptive term " thin shell substance " (p. 168) clearly means in comparison with that of a *Natica*. Any student of conchology has, or should have, a conception of a *Natica* and its thick shell substance. That a shell is thinner than *Natica* does not mean it is thinner than *Viviparus*.

Sometimes morphological differences of seemingly minor importance may well turn out to be distinctive characters when such differences are substantiated by considerations of time and space. In dealing with an extinct fauna, time constitutes a far more important factor.

Referring to habitat conditions I have stated clearly that there are two fossiliferous beds at the locality in Skye from which my specimens were obtained, namely a band of fine-grained cementstone about 4 inches thick overlying a bed of limestone 1 foot thick. The contact between the beds is even and there is actually but little change in colour or lithologic character. Under such circumstances there is small ground for the assumption of abrupt change in habitat conditions from marine to freshwater. If a " slow uplift " ever took place, then the change should be gradual; I have mentioned the possibility that estuarine conditions existed, and that gastropods of marine origin were carried to the deltaic area by sea current, wave, and tidal actions.

Moreover, some of those who have commented on my paper suggest the possibility that freshwater gastropods were carried into the sea by " an exceptional flood ". Since dead molluscan shells are generally precipitated to the bottom and buried in the sediments at the bottom, it certainly would require " an exceptional flood " to drift large numbers of shells of *Viviparus* a considerable distance along a river course. But at same time, as such a flood would have also carried all loose objects, pebbles and gravel, these would form a kind of conglomeratic bed, or at least a bed of coarse texture. The *Bathonella*-bearing bed exposed in Skye consists of sandy limestone of fine texture, in North Oxfordshire of " marl " and in France also of limestone. One can hardly see how fossil beds of such fine texture can be attributed to " an exceptional flood " followed by " minor floods ", or how nature could have sorted out and carried elsewhere everything in the debris but these supposed freshwater gastropods.

In reference to Charophyte gyrogonites and *Metacypris*, Mr. Sylvester-Bradley has mentioned that he has found gyrogonites also in beds usually regarded as marine. Species of *Metacypris* have been found in beds of brackish origin. The Jurassic and Cretaceous species attributed to " *Cyrena* " are of brackish and perhaps sometimes of purely marine origin, and are nowadays referred to the genera *Neomiodon* and *Protomiodon*. *Valvata*-like species found in Bathonian beds, as well pointed out by Anderson and Cox (p. 118), may belong to *Tornus*. As a result of such corrections, the list given by Mr. Watson (p. 23) of five Bathonian freshwater genera, which is compiled from various sources, has to be reduced to one, namely *Viviparus*, and for this I have had the privilege of proposing the name *Bathonella*, and I have considered it and still consider it to be of marine origin.

TENG-CHIEN YEN.

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REVIEWS

PRINCIPLES OF STRUCTURAL GEOLOGY. By C. M. NEVIN. pp. xiii and 410, with 250 text-figs. and 7 plates. J. Wiley and Sons, Inc., New York, and Chapman and Hall, London. Fourth edition, 1949. Price 48*s*.

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W. B. H.

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